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ABSTRACT

This compilation of references on calculators covers the uses of calculators in the primary, middle, and lower secondary grades. It includes the greater part of the relevant literature available in the English language up to the summer of 1981. Selection of the American literature is rigorous, while the list of recent publications in the United Kingdom has been made as complete as possible. The annotations are designed to give a brief indication of the contents and possible significance of each publication. Chapters focus on general sources, calculator hardware and specifications, miscellaneous references, calculators in the curriculum, and research. (MNS)

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# CALCULATORS IN THE ELEMENTARY MATHEMATICS CURRICULUM

## An Annotated Bibliography

by
Christopher A. Gregory

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## Foreword

This compilation of references was originally conceived as one part of a programme of research undertaken during the tenure of a Mathematics Teacher Fellowship at the Centre for Studies in Science Education, University of Leeds, and sponsored by the City of Bradford L.E.A.. Undertaken initially as a means of clearing the ground for some serious development work in the writer's own school, it acquired a life of its own and was pursued in the belief that such a bibliography might serve a useful purpose as a reference base for teachers and teacher educators intending to explore this field. The literature surveyed, often repetitive and always uneven in quality, proved to be far more extensive than first imagined, and some of the more interesting and enduring items appeared to be largely unknown and, in practice, inaccessible to most teachers in this country.

The project could hardly have been completed without the co-operation of many individuals and institutions: most of all, Dave Carter, Tony Orton and Geoff.Wain of the Science Education Centre, University of Leeds, for their encouragement at all times; the staff of the Brotherton Library, University of Leeds, for obtaining much of the American literature; Angela Terry and Maureen Pedder, for their efforts in transforming a lengthy and exceedingly messy manuscript into a presentable document; Gordon Browne, Mathematics Adviser to the Bradford L.E.A., for his sponsorship of the project; William Wynne Willson, University of Birmingham, for his invitation to a meeting of the Schools Calculator Working Party; Barry Blakeley and David Johnson, Chelsea College; Ken Tyler, Leicestershire Primary Calculator Project; and Russell Langham, Co.Durham L.E.A., for copies of publications and a variety of information.

The work was greatly facilitated by correspondents in North America: Marilyn Suydam of the Calculator Information Center, Columbus, Ohio; Alexander Tobin, School District of Philadelphia; the National Council of Teachers of Mathematics, Reston, Virginia; Michael Silbert, Board of Education, Hamilton, Ontario, and the Office of the Alberta Teachers' Association.

Finally, my thanks are due to Mr.Salim of Texas Instruments and to all those publishers who so generously supplied copies of, and information about, their publications.

C.A.Gregory
August 1981

FOOTNOTE:

THE PAGE REFERENCES CITED REFER TO THIS TEXT AND NOT TO THE ORIGINAL PUBLICATION.

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## INTRODUCTION

While it was originally intended to concentrate upon the uses of calculators in the Middle School Years (9-13), it soon became apparent that this category was quite meaningless in relation to the available literature. The present compilation aims to cover the uses of calculators in the 'elementary' mathematics curriculum i.e. potentially the Primary/Middle/Lower Secondary School age range. Even then, no clear boundaries exist and a number of works are included which, although they refer to more advanced applications, have perhaps something of value to say to teachers of younger children.

It is believed that the greater part of the relevant literature available in the English language has been surveyed up to the summer of 1981. The final collection of references is necessarily selective and a number of items were eventually excluded on the grounds that they had only been of ephemeral interest and had been overtaken by more recent events, or were simply repetitive versions of more interesting papers. Selection of the American literature has had to be rigorous, while, on the other hand, the list of recent book publications in the United Kingdom has been made as complete as possible. The annotations included are necessarily idiosyncratic, to some degree at least, but are intended to give a brief indication of the contents and possible significance of each publication.

The categories employed in the bibliography are far from exclusive and, for this reason, indexes of Authors and Institutions have been included.

The next few years must surely see an expansion of calculator use with young children as the motivating power and potential educational uses of calculators become more widely recognised. Such development is, indeed, essential if future mathematics curricula are to retain any measure of relevance and public credibility. The output of publications, at least, will undoubtedly increase, including both a large number of American works re-published in this country and a growing collection of home-produced curriculum materials.

It is worth noting that a number of interesting articles have appeared in the magazines Creative Computing and Calculators/Computers which are available on order from some suppliers of microcomputers and computing publications.

Finally, it seems discourteous not to mention Hugh Neill's Use of Electronic Calculators in the Sixth Form (Co.Durham Educ.Committee) which, although going far beyond the concerns of this bibliography, gives some particularly valuable insights into what calculator assistance might offer at this level of education.

## A NOTE ON FILMS

The existence of the following 16mm films is noted:

1) Expanding Math Skills with the Minicalculator

A series of three films intended for teacher training, and three further films for use with children, along with a multi-media kit 'Math on Display'.

Developed and produced in the United States and marketed by Encyclopaedia Britannica Educational Corporation. The British distributors are Fergus-Davidson Associates, although the current availability of the materials seems to be in some doubt.

2) The Calculator goes to School

A film intended for teacher education and in-service work which contains some interesting classroom sequences.

Available from Mr.I.Salim of Texas Instruments.

## CHAPTER 1

## GENERAL SOURCES

### (i) Early Reports

By 1974, hand-held electronic calculators were selling in sufficient numbers, in the industrialised countries at least, that their low price opened up the possibility of their widespread use in education. Early responses to the challenge ranged from enthusiastic acceptance of extensive use to the expression of grave misgivings about their impact on schools.

In the same year, in the United States, the National Council of Teachers of Mathematics Board of Directors issued the following policy statement:

> 'With the decrease in the cost of the minicalculator, its accessibility to students at all levels is increasing rapidly and Mathematics teachers should recognise its potential contribution as a valuable instructional aid. In the classroom, the minicalculator should be used in imaginative ways to reinforce learning and to motivate learners as they become proficient in Mathematics.'

While, in retrospect, this statement may be viewed as erring on the side of caution, it provoked considerable interest and, by 1976, a steady stream of papers was appearing in the American journals.

In 1975 and 1976, four major reports were published in the United States. These constitute a convenient starting point since most of the issues with which educators have since tried to come to terms were raised in one or more of them.

---

NACOME (National Advisory Committee on Mathematics Education)
Overview and Analysis of School Mathematics, Grades K-12
Conference Board of Mathematical Sciences
Washington D.C. 1975

(ERIC:ED 115 512
- also available from N.C.T.M.)

NACOME was appointed in 1974 and in the following year its report, influential in the U.S.A. since that time, was published.

Four references are made to the use of calculators.

Recommendations include decrease of emphasis on manipulative skills, and increased emphasis on estimation/approximation, order of magnitude and the interpretation of numerical data. An earlier introduction to decimals, negative numbers, scientific notation etc., in the elementary school, is proposed and the recommendation is made that calculators should be freely available from grade 8 upwards. Some basic questions about the effects of calculator use are asked and a need expressed for new instructional materials and curricular revision.

---

NIE Conference on Basic Mathematical Skills and Learning
(Euclid, Ohio Oct.1975)

National Institute of Education,
Washington D.C. 1975

Vol.I: Contributed Position Papers

(ERIC:ED 125 908)

Vol.II: Reports from Working Groups

(ERIC:ED 125 909)

The report of a Conference convened by the NIE, consisting of 33 position papers, group reports and a general essay.

A central concern is the question of the extent to which calculator use will affect any definition of basic skills. Topics discussed include placement/emphasis of topics in the curriculum, the place of pencil and paper algorithms, the calculator as an arithmetical aid and its impact on problem solving.

The report advocates research into 'true functional needs' and into the potential uses of calculators.

In the general essay, Rising and Hill advise against premature constraints on calculator usage and stress the need for good curriculum materials.

---

Suydam,M.N.(ed.)
Electronic Hand Calculators: The Implications for Pre-College Education: Final Report.

National Science Foundation,
Washington D.C. 1976

(ERIC:ED 127 206 - abbreviated version
ERIC:ED 127 205 - full version with appendices)

This report was a major attempt at a critical analysis of the role of the calculator. A range of beliefs and reactions concerning calculators are identified from questionnaires addressed to teachers, supervisors, mathematics educators and publishers. Current arguments for and against calculator use are spelled out and wide range of suggestions for research made.

A detailed list of recommendations are set out and include many specific curricular suggestions.

The appendices include papers by:
Immerzeel, Ockenga and Tarr, (see refs. in Chap.4)
Pollak {see Pollak(p.36)}
Bell and Usiskin (see Usiskin p.14)
and
Weaver,J.F.
'Some suggestions for Needed Research on the Role of the Hand-Held Electronic Calculator in relation to School Mathematics Curricula'. (Appendix E)
Weaver here draws a distinction between Calculator-assisted (CA), Calculator-modulated (CM) and Calculator-based (CB) mathematics curricula.

---

Esty,E. and Payne,J.(eds.)
Report of Conference on Needed Research and Development on Hand-Held Calculators in School Mathematics

National Institute of Education/
National Science Foundation,
Washington D.C. 1976
(ERIC:ED 139 665)

This report effectively laid down a framework for future research and development. The inevitability of calculator impact on schools is acknowledged and a number of relevant questions are identified.

The recommendations made include:

- dissemination of information
- development of an information base
- immediate curriculum development
- long-range curriculum development
- research and evaluation
- teacher education.

---

Some significant commentaries on these reports exist and provide useful summaries of them:

Bell,M.S., Esty,E., Payne,J. and Suydam,M.N.
'Hand-held calculators: Past, Present and Future'
in Crosswhite,F.J.(ed.)
Organising for Mathematics Instruction
Yearbook N.C.T.M. 1977

The four reports are discussed in some detail and a brief survey of American curriculum development projects is given.

---

Mathematics Teacher 1976

This issue includes a summary of the NACOME report and extended commentaries by

Kline,M. 'Implications for Curriculum Design'
Taylor,R. 'Implications for Teaching: K-12'
Trimble,H. 'Implications for Teacher Education'

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Werner,M.
'The Hand-held calculator and its impact on Mathematics curricula'
School Science and Maths 80, Jan.1980

Resistance to calculator use is noted, especially from those who would equate mathematical competence with computational skill. The present state of mathematics education is seen as unsatisfactory and 'such new initiatives imperatives rather than merely desirable'. Many references are made to the four main reports and also to the NCSM statement {see NCSM(p.40)}.

---

(ii) Calculator Information Center

In 1978, the Calculator Information Center was established, under the auspices of ERIC (Educational Resources Information Clearinghouse), at Ohio State University, Columbus. Under the direction of Ms.Marilyn Suydam, it has, over the last three years, produced a steady stream of occasional Bulletins, as well as some more substantial publications. It remains the most comprehensive source of information on calculator use.

Apart from disseminating information, the Center invites all interested parties to contribute information on publications and activities.

The following publications are currently available; others are referred to elsewhere:

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Suydam,M.N.
Calculators: A Categorised Compilation of References
Calculator Information Center,
Ohio State Univ., Columbus 1979
(ERIC:ED 171 572)
(also available in paper copy from C.I.C.)
An extensive bibliography, including most, if not all, worthwhile references on calculators available, up to that time, in the United States. While many are not easily obtainable in the U.K., the compilation has been one of the best starting points for exploring the literature. A list of Bulletins published, and an index, are included.

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Suydam,M.N.(ed.)
Information Bulletins from the Calculator Information Center:
Bulletins 1-7 1979
(ERIC:ED 171 574)
From time to time Information Bulletins on special topics have been published. The first seven, collected together here, cover: Types of calculators, activities for the secondary school, calculator selection for elementary schools, notes for administrators, leading a calculator workshop, using calculators in grades 1-3, activities for grades 4-6.
(Some reprints have recently been available from N.C.T.M.).

---

Suydam,M.N.(ed.)
Reference Bulletins from the Calculator Information Center:
Bulletins 1-18 1979
(ERIC: ED 167 426)
All these Bulletins list references on the uses of calculators in education in several categories: Articles on instruction with calculators, books on calculator applications, calculators at post-secondary level, research, desk calculators, pros and cons, selecting a calculator. Many references are annotated and some Bulletins have an introductory synthesis.

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Current Reference and Information Bulletins are available directly, free of charge, from the Calculator Information Center.

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Suydam,M.N.
The Use of Calculators in Pre-College Education: A State of the Art Review 1979
(ERIC: ED 171 573)

Two reviews are included, dated April 1978 and May 1979. Each presents a concise summary of the then current state of the use of calculators in schools, research on calculator effects, and the development of materials. Many references are included.

---

Suydam,M.N.
Using Calculators in Pre-College Education
(Third Annual State of the Art Review)
Aug. 1980

The most recent summary of developments - prices, calculator ownership, research, surveys of attitudes and the development of instructional materials.
(available directly from C.I.C.).

---

Suydam,M.N.et al
Ohio Regional Conferences on Mathematics Education
Center for Science and Math.Education, Ohio State Univ., Columbus 1978
(ERIC: ED 164 328)

A varied collection of materials produced for five regional conferences for elementary mathematics supervisors and educators. Directions on the use of the calculator are given and problem solving and 'basic skills' are emphasised. 'Resource packets' are also included, containing reprints of a wide range of materials, including some C.I.C.Bulletins.

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Suydam,M.N.
Calculators: A Categorised Compilation of References
Calc.Infn.Center Dec. 1980
(available in paper copy)

The most recent compilation produced by the Center, offering some overlap with the present work. Apart from American publications there are many from European sources including some in French, German and Russian.

---

(iii) United Kingdom

Most of the readily available references are to be found in the two main teaching journals: Mathematics in School and Mathematics Teaching. In the latter journal especially, apart from a steady stream of articles, there has been much editorial comment over the last few years which is worth consulting and a comprehensive list of articles on calculators appearing in M.T. is available from the office of the Association of Teachers of Mathematics.

Some worthwhile popular articles have been published in the Times Educational Supplement and some further reports from the Mathematical Association are expected in 1981.

---

Blakeley,B.H.
'Some Calculator Questions'

Mathematics in School 7, 2 1978

A whole range of basic questions about the use of calculators is posed - basic skills, old and new, new problems and possibilities for teaching, public relations, difficulties for teachers etc..

---

Blakeley,B.H.
'Calculated risks'

Times Ed.Suppl. 17 Oct. 1980

The most up to date general summary of what is happening so far published in the U.K. The principal results of research, and the British curriculum projects, are described.

---

D.E.S.
Mathematics 5-11: A Handbook of Suggestions
(HMI Series: Matters for Discussion)

HMSO 1979

This includes a general but adequate discussion of the present and potential uses of calculators in school. Their uses as calculating aids are pointed out but also their potential as learning aids - 'a point which is at present considered by too few teachers'. The necessity for all children to learn to use a calculator is emphasised, and a range of possible applications is indicated.

---

D.E.S.
Aspects of Secondary Education
(A survey by H.M.Inspectorate of Schools)

HMSO 1979

Part of Chapter 7 is concerned with the possible uses of calculators, stating that 'the new approaches which are possible in mathematics at all levels of ability, and the wider range of problems which can be attempted, have still to be exploited.' The possibilities for the future are described in a general manner, and the need to radically re-think syllabuses.

---

Dubbey,J.et al
'Calculators'

Times Higher Ed.Suppl. 28 Nov. 1975

A collection of seven articles, now rather dated but still of possible general interest, on the history of calculating machines, calculator specifications, and applications (higher and further education).

---

Edsall,D.L.(ed.)
Calculators have come!

Mathematical Association 1976

A report produced by members of the Computers and Calculators sub-committee. Of particular interest in the present context are:

Girling,M.S.
'Basic Numeracy in the Electronic Age'
- the need for a new definition is stressed.
Watson,F.R.
'Using a calculator to investigate patterns'
- a number of examples are given.
Edsall,D.L.
'Some possible effects of calculators on secondary school mathematics'.

---

Fielker,D.S.
'Calculators: News, Views, Reviews'

Mathematics Teaching 88 1979

A wide-ranging discussion of current publications, research and development and teacher attitudes. The dearth of calculator-based activities is noted, as well as lack of attention to the essential problem of finding efficient algorithms.

---

Fitzgerald,A.
'School mathematics and employment at 16+ with particular reference to commercial work'

Mathematics in School 9, 3 1980

Although its concerns are beyond the scope of the present work, this article includes references to calculator use (or non-use) in schools which are of wider interest.

---

Gattegno,C.
'Children and Mathematics: A New Appraisal'

Mathematics Teaching 94 1981

In the context of a wide-ranging discussion of issues in mathematics education some remarks are made about computational competence and the role of calculators and microcomputers. It is considered that 'new algorithms will be created in the near future and will point the way towards saving the irretrievable time consumed in obsolete uses of the brain, pen and paper and making that time available for more human endeavours'.

---

Gregory,C.A.
Electronic Calculators in the Elementary Mathematics Curriculum
Centre for Studies in Science Education, University of Leeds Jan. 1981

A general survey of the early American literature is presented, along with some historical considerations, notes on calculator specifications, a discussion of present research and development needs, and the results of surveys of calculator ownership and use.

---

Gribbin,J. and Gribbin,M.
'Calculators for Kids'
New Scientist 82, Dec. 1979

A short, popular article, cautious in its advocacy of calculator use. Most of the article concerns itself with the uses of pre-programmed machines and there is little discussion of the possible uses of calculators as such.

---

Johnson,D.C.
Figures and Chips
Inaugural Lecture, Chelsea College 1979

Apart from a brief survey of the history of calculating machines and computers, the greater part of the lecture is devoted to a discussion of numeracy and some features of new curricula, assuming ready access to calculators.

---

Kaner,P.
'The Calculator: an imperative in Secondary School'
IMA Bulletin 16, 8/9 1980

A general statement of the rationale for the use of calculators at secondary school level.

In the same issue, see Watson (p.37) and Blakeley (p.35).

---

Knowles,F.
'Books for Calculators'
Mathematics Teaching 95 1981

A collection of reviews of some publications on calculators which have recently appeared in the U.K. - all referred to elsewhere in the bibliography.

---

Lindsay,I.D.
'Calculators in Perspective'
Mathematics in School 6, 4 1977

A discussion of the challenge to secondary schools of calculator use is followed by an attempt to put such changes in an historical perspective. The lack of coherent policies is deplored and the continuing need for basic arithmetical skills and knowledge of the uses and limitations of calculators is stressed.

---

McAlhane,B.
'Calculators and Exams.'

Where 125, Feb. 1977

An interesting popular survey of the arguments for and against the use of calculators in schools. The then current examination regulations are described as well as notes on choosing a calculator.

---

McIntosh,A.J.
'Calculators in the Classroom?'

Junior Education Jan. 1979

An article aimed at Primary School teachers, mentioning specifically the Shell Centre report (p.72) and the results of research, while giving a variety of general information and advice.

---

Quadling,D.
'A Nation of Button Pushers'

Mathematics in School 4, 3 1975

A rather dated discussion of some basic issues - the role of calculating aids, examinations and numeracy.

---

Reynolds,P.
Editorial: 'A New Electronic Age'

Mathematics in School 1, 5 1972

A very early account, perhaps of some historical interest, of the availability of 'cheap' calculators and the possible educational implications.

---

Reynolds,P.
'An impression of a seminar on calculators in schools'

Mathematics in School 5, 3 1976

A brief and general note which includes some facts concerning calculator sales in 1975.

---

Reynolds,P.
'3 ICME Karlsruhe 1976'

Mathematics in School 5, 5 1976

A brief account of the proceedings of the 3rd International Conference on Mathematical Education pertaining to the use of calculators and computers.

---

Scottish Central Committee on Mathematics
'Calculating machines in schools'

Bull.of Scott.Centre for Maths., Science and Technol. Education June 1977

{reprinted in Neufeld,K.A. (p.15)}

A general and cautious statement of the impact on education of technological change. Basic numeracy is discussed at length and it is concluded that calculators have little application in primary schools, and should only be used when a 'substantial degree' of arithmetical competence has been acquired.

---

Valéry,N. et al
'The Calculator Explosion'
(New Scientist Calculator Supplement)

New Scientist Nov. 1975

A collection of four articles on the calculator industry, calculator design and specifications, and the calculator's likely impact on the role of arithmetic.

---

Watson,F.R.
'Useful References on Calculators'

Mathematical Association 1981
(available from Univ.of Keele)

A list of references, both British and American, prepared for the Computers and Calculators sub-committee of the Mathematical Association. It contains many of the references cited in the present compilation.

---

Webb,N.
'Calculators and Computers: Educational Advantages and Dangers'

Mathematics in School 5, 5 1976

A general survey of the situation and the prospects for the future. Some of the advantages of calculator use are pointed out. Webb notes the futility of resisting technological changes and urges us to 'embrace new technological development wholeheartedly, exploit its advantages to the full, but react quickly and effectively to compensate for its disadvantages as they become apparent'.

---

(iv) United States

The two teaching journals, Arithmetic Teacher (elementary/junior high school level) and Mathematics Teacher (junior high/high school/college level), remain the richest source of material. A number of references, scattered throughout this bibliography, are derived from the Arithmetic Teacher 'Minicalculators' issue (Nov.1976) and the Mathematics Teacher 'Calculators/Computers' issue (May 1978). Much of the best material is also reprinted in Burt (p.11).

The two special issues and Burt's compilation are available directly from N.C.T.M.

---

Bell,M.S.
'Calculators in elementary schools? Some tentative guidelines and questions based on classroom experience'
Arithmetic Teacher 23, 7 1976
(Minicalculators issue)

A general discussion of the role of calculators, based on work with children from grade 1 upwards. The benefits and problems of calculator use are discussed and the need to consider the required specifications is underlined. This is still, perhaps, one of the best general surveys of the field.

---

Bell,M.S.
'Calculators in secondary school mathematics'
Mathematics Teacher 71, 5 1978
(Calculators/Computers issue)

The possible long term effects of calculator use are discussed in some depth, including the re-definition of 'basic skills' and the opportunities which may present themselves in continuing education. Bell endorses the recommendations of the NSF/NIE report {Esty and Payne(p.3)} and warns that 'if we fail, a substantial part of mathematics education may eventually go the way of instruction in handwriting, Greek or Latin'.

---

Burt,B.C.(ed.)
Calculators: Readings from the Arithmetic Teacher and the Mathematics Teacher
N.C.T.M. 1979

A good collection of sources from these two American journals, including many cited in this bibliography.

---

Caravella,J.R.
Minicalculators in the Classroom
National Education Association 1977
(available from N.C.T.M.)

A general popular introduction to the uses of calculators in education. Some basic questions are considered and a range of possibilities indicated. The main developments in the U.S.A. are described, along with some of the current curriculum projects. There is also a chapter on specification {see Caravella(p.22)} and a considerable number of references.

---

Driscoll,M.J.
Elementary School Mathematics Annotated Bibliography
Central Midwestern Regional Educational Laboratory, Inc.,
R.& D.Interpretation Service, St.Louis. Mo. 1979
(ERIC:ED 183 378)

References on mathematics education are given, in 17 categories, each with very good abstracts. A small number of these relate to the use of calculators.

---

Etlinger,L.E. et al
The Calculator in the Classroom: Revolution or Revelation
Chicago State Univ. 1978
(ERIC:ED 191 740)

The uses of calculators in school are discussed and it is suggested that guidelines be established for their use. Since they constitute no threat to 'learning the fundamentals' it is recommended that they should be used as soon as the basic operations are understood.

---

Hawthorne,F.S.
'Hand-held Calculators: Help or Hindrance?'
Arithmetic Teacher 20, 8 1973

An early discussion, written at a time when calculators were becoming reasonably cheap, which is largely of historical interest. Very cautious views are expressed.

---

Hopkins,E.E.
'A modest proposal concerning the use of hand calculators in schools'
Arithmetic Teacher 23, 8 1976

A brief but interesting attempt at a broad historical overview of societal reactions to technological change. Hopkins argues that, in the course of any such change, old skills are lost and new ones acquired and that the calculator is simply a different calculating device, though immensely more powerful than pencil and paper.

---

Immerzeel,G.
'The Hand-held Calculator'
Arithmetic Teacher 23, 4 1976

Since the rate of calculator ownership is growing, it is argued that there is an urgent need to explore the uses of calculators, to prepare for future universal ownership.

---

Machlowitz,E.
'Electronic calculators - friend or foe of instruction?'
Mathematics Teacher 69, 2 1976

A general discussion of the range of possible uses of calculators. Table-top models are especially recommended. Some reservations are made in the hope that certain questions may be resolved by research into extensive use.

---

Maor,E.
'The pocket calculator as a teaching aid'
Mathematics Teacher 69, 6 1976
{reprinted in Neufeld,K.A.(p.15)}
A general discussion of the prospects for the use of calculators in the classroom is followed by a survey of the areas of mathematics to which their use might be particularly relevant.

---

May,L.J.
'One Point of View: Change and Changelessness'
Arithmetic Teacher 27, 9 1980
Some general comments on the significance of wide calculator use and the need for curricular revision are made. It is considered that teaching children to use calculators should be a priority, leaving more time for problem solving, although a thorough grasp of basic number facts will still be needed.

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Munson,H.
'Your District needs a policy on Pocket Calculators'
Arithmetic Teacher 25, 1 1977
The present confused situation is deplored and the need for coherent policies emphasised.

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N.C.T.M.
Calculator Information Resources
(latest edition) Nov. 1980
A categorised list of references on calculators.
(available from N.C.T.M.)

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N.C.T.M. Board of Directors
An Agenda for Action: Recommendations for school Mathematics of the 1980s.
N.C.T.M. 1980
(available from N.C.T.M.)
A whole range of recommendations are offered as the basis for policies on mathematics education in the 1980s. No.3 proposes that 'mathematics programs take full advantage of the power of calculators and computers at all grade levels'.

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N.C.T.M. Instructional Affairs Committee
'Minicalculators in Schools'
Arithmetic Teacher 23, 1 1976
(also in Mathematics Teacher 69, 1 1976)
Nine justifications for using hand-held calculators in schools are given, with specific examples of uses. An early and comprehensive statement of policy on the part of the N.C.T.M.

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Reys,R.E.
'Calculators in the Elementary Classroom: How can we go wrong?'
Arithmetic Teacher 28, 3 1980

A broad discussion of current abuses of calculators and mistaken policies. The results of research so far are briefly reviewed. It is concluded that 'hand calculators hold great potential as an instructional tool for the elementary school'.

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Rising,G.
The New Calculation in Education: a Research Agenda
1978
(ERIC:ED 170 169)

One of the better general reviews of the field which attempts to lay down a preliminary framework for research into the effects of calculator use on mathematics learning. A very broad definition of 'research' is suggested and the trend of current research criticised. Curricular proposals are made. The exploration of the calculator as a mechanism in its own right is proposed and some essentially philosophical questions are raised.

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Rogers,J.J.
'The electronic calculator - another teaching aid'.
Arithmetic Teacher 23, 7 1976
(Minicalculator issue)

The essential characteristics of enduring teaching aids are identified. The hand-held calculator is considered to be a teaching aid of lasting value and its free use is recommended.

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Shumway,R.J.
'Hand-held Calculators - where do you stand?'
Arithmetic Teacher 23, 7 1976
(Minicalculator issue)

Arguments for and against the use of calculators are reviewed. What the current needs for pencil and paper algorithms are is considered, and the extent to which calculators can be used without hindering their development.

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Usiskin,Z.P.
'Are calculators a crutch?'
Mathematics Teacher 71, 5 1978
{Calculators/Computers issue:
revised version of
Usiskin,Z.P. and Bell,M.S.
'Calculators and School Arithmetic: Some Perspectives'
Appendix F of Suydam,M.N.(ed.) 'Implications....' report,(p.2)}.

The 'crutch' premise is questioned and the calculator is considered as a 'tool'. The crucial issue is seen as not how calculations are accomplished but how to use arithmetic to solve problems that matter to people. This is one of the most pertinent discussions of the issues.

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(v) Canada

Apart from a number of articles in regional journals, two reports are particularly worthy of attention:

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Neufeld,K.A.(ed.)
Calculators in the Classroom
(Math.Monograph no.5)
Alberta Teachers' Association 1977

A compendium of papers, mostly published elsewhere, covering a wide range of concerns, from calculator specifications to curriculum materials. Some papers are referred to elsewhere in the present collection, but also of note is a report by Max Bell on a Chicago conference. One of the best collections of references. (Available at $5 from A.T.A.).

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Silbert,M.R.
The Hand Calculator and its Impact on the Classroom: Report and Recommendations
Board of Education,
Hamilton, Ontario 1977

A very broad survey of historical developments and current issues, along with a summary of research findings available at the time. Detailed recommendations include use of calculators in all subject fields in secondary schools, including tests and exams, and the gradual provision of calculators for all students in grades 7-9. Future developments are forecast and appended are a chronology of calculator-related events (in Hamilton) and an extensive bibliography.

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(vi) Australia

In compiling this bibliography, the literature from Australia and New Zealand has not been examined in detail. One paper is referred to elsewhere {Stephens(p.39)}.

Otherwise, one whole issue of

Australian Maths Teacher 35, 4 1979

contains a number of relevant articles, viz.

McCrae,B.
'Calculators and Numeracy'
Foster,B.
'Calculators and Primary Mathematics'
Koop,A.J.
'Calculators in schools: some curricular considerations'
Phillips,J.W.
'Periods with calculators'
Fearnley-Sander,D.
'The programmable calculator: a computer for every pocket'
Feighlin,A., Alonso,J.R.F., Thompson,W. and Stephens,M.
'Victorian survey on calculator usage in post-primary schools'

(vii) Other countries

The best general reference for world-wide developments is:

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Suydam,M.N.
International Calculator Review
ERIC/SMEAC, Columbus, Ohio 1980

This includes reports from sixteen countries on the uses of calculators in schools, a synthesis and a list of references.
{See also Ethelberg-Laursen (p.77) and Hedren (p.72)}

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There appears to be little other published material relating to calculator use in Third World countries. The following two references seem to be the only ones easily available.

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D'Ambrosio,U.
'Issues arising on the use of hand-held calculators in schools'
Int.J.Math.Ed.Sci.Technol.9, 4 1978
(ERIC:ED 144 814)

Some common objections to calculator use are refuted. Calculators are considered as an aid in adjusting imbalances between have and have-not groups, and nations. The work of some Brazilian projects is described and the use of calculators in modelling real problems is proposed.

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Zepp,R.A. and Selwyn,J.B.
'A course in Essential Mathematics'
Mathematics Teaching 92 1980

A general mathematics course for undergraduates at the University of Lesotho is described. Learning to use a calculator was an integral part of the course.

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## CHAPTER 2

## CALCULATOR HARDWARE AND SPECIFICATIONS

In 1967 Texas Instruments developed the first four-function calculator based on a single integrated circuit and by October 1971 the first, though relatively expensive, hand-held calculator was on sale in the United Kingdom. Since then sales have soared, reaching a peak in 1978, and prices have fallen until at the present time, a basic calculator need cost no more than £5.

Surveys of available models are rapidly outdated but general accounts of calculator architecture and specifications which are a few years old may still be of interest and value in selecting calculators for personal and educational use.

A very good general reference is:

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Green,D.R. and Lewis,J.
Science with Pocket Calculators Wykeham 1978
(see p.51)

Though written for owners of 'advanced' calculators, with the emphasis on applications in upper secondary school mathematics and science, the first six chapters comprise a detailed handbook, describing types of calculators, specifications and a discussion of logics. The circuitry of a calculator is described in some detail and there is a wide range of references, not only applications but technical references not readily found elsewhere.

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(i) Hardware design

McWhorter,E.W.
'The Small Electronic Calculator' Scientific American March 1976
The historical development of the pocket calculator is outlined and the computer-like structure of the microprocessor is described fully. The future evaluation of the calculator and the nature of future specifications are mentioned - many of the latter now realised.

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(ii) General surveys:

a) Calculators

Albrecht,R.L. et al
'The Role of Electronic Computers and Calculators'
Chapter 6 of Berger,E.J.(ed.)
Instructional Aids in Mathematics 34th Yearbook N.C.T.M. 1973
A necessarily outdated account of computers and calculators in mathematics instruction, but of historical interest. An extensive bibliography is included.

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Blakeley,B.H.
'Calculated Offerings' Times Ed.Suppl. 13th June 1980
An up to date general survey of available types of calculators, including specifications and price ranges.

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Flisher,F.W.
'The Electronic Road to Better Mathematics'
Education 147, 30th Jan. 1976
A general description of the calculator market with a discussion of the different categories of calculator available, user specifications and suggested applications.

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New,P.J.
'Calculators in Mathematics' IMA Bulletin 16, 8/9 1980
A brief survey of the field with an extended account of the specifications of the more advanced types of calculators.

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b) Specialised models and electronic games:

Blakeley,B.H.
'Intelligent Machines' Times Ed.Suppl. 1 Aug. 1980
A wide range of 'inside-out' calculators is reviewed e.g. Little Professor, Dataman and other non-mathematical electronic games.

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Blakeley,B.H.
'Mathematical Dialogues' Times Ed.Suppl. 17 April 1981
Detailed reviews of two new Texas Instruments' products - 'Speak and Maths' and the TI30 LCD calculator, designed on the basis of the results of a survey of school practices and preferences.

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McCarty,G.
'Display Calculators bring a new dimension to teaching'
Audio-Visual Instruction 24, 6 1979

Some models of calculators intended for use with an overhead projector are described.

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(iii) Calculator Specifications:

A number of generalised accounts of calculator specifications have been published over the last few years including many in the Handbooks cited later, along with recommendations for calculators for school use.

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Caravella,J.R.
'Selecting a minicalculator' Arithmetic Teacher 23, 7 1976 (Minicalculator Issue)
(also in Mathematics Teacher 70, 4 1977)
A very wide range of specifications for basic and scientific calculators is described, along with key sequences.
{See also Caravella (p.11)}.

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CET(Council for Educational Technology)
USPEC 25: A Guide to the Selection of Electronic Calculators Oct. 1978
An up to date and easily-read description of the full range of specifications to be considered when purchasing calculators for school use - logic, keyboard functions, power supply etc..

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Dolan,D.T.
'So you want to buy a calculator'
{in Neufeld,K.A.(p.15)}
A clear and well-written account for beginners, written by a working party of teachers, including recommended features for Junior High School use.

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Fielker,D.S.
'Electronic Calculators' Mathematics Teaching 64 1973
Although inevitably dated, this remains one of the most informative general accounts of the nature of electronic calculators and the implications of their extensive use. It includes a basic glossary of technical terms and details of current manufacturers.

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Harling,R.
'Calculated Options' Times Ed.Suppl. 13 March 1981
Presented as 'guidelines for choosing a basic calculator for Primary and Middle School children'. The discussion of the full range of possible specifications is simple and straightforward although little guidance on how to interpret the specifications is offered. It is concluded that 'an ideal calculator for Primary and Middle Schools probably doesn't exist'.

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Jesson,D. and Kurley,P.
'Specifications for Electronic Calculators'
Mathematics Teaching 70 1975
{Also in Mathematics Teacher 69, 1976
and Neufeld,K.A. (p.15)}
A carefully considered and detailed list of recommended specifications for a basic calculator.

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Lewis,J.(ed.)
'Essential and desirable features on electronic calculators for use in the 11-16 year range'.
Mathematics in School 6, 5 1977
A brief set of recommendations for a basic calculator for schools prepared by a joint working party of A.T.M., Mathematical Association and A.S.E..

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New,P.J.
'Choosing an Electronic Calculator'
Mathematics in School 6, 1 1977
An extended technical discussion of criteria to be considered when purchasing calculators for school use.

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(iv) Calculator logics:

There are many discussions in the literature of the logics built into calculators, and their relative merits.

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Johnson,D.C.
'Types of Calculators: Let's use more appropriate descriptors'
Mathematics in School 9, 4 1980

The adequacy of the description 'algebraic logic' is questioned and a categorisation of calculator logics as 1) arithmetic 2) algebraic and 3) RPN is proposed.

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Mitchell,C.E. and Blume,G.W.
'An Introduction to Calculator Logic Systems'
Mathematics Teacher 73, 8 1980

A comprehensive account of calculator logics according to a classification similar to that proposed by Johnson. The advantages and disadvantages of each are discussed and calculators employing RPN logic recommended for serious consideration.

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(v) Consumer Reports:

Although Consumer Reports inevitably refer to calculator models which are soon obsolete, and are aimed at a very wide, not necessarily educational, audience, the following are of sufficient general interest to be worth referring to:

Which? Consumers' Association

- has carried several reports on calculators which include, apart from the usual test reports, more general guidance for prospective purchasers.

The Reports published so far have been:

Dec.1973 Small Electronic Calculators:
Twenty, now obsolete, models are tested and there is an extensive discussion of specifications.

Dec.1976 Calculators:
Apart from the tests, this includes a section entitled 'About Calculators' - a useful and very readable introduction to calculator uses and specifications, with a description of the functions typically available.

Sept.1977 Calculators: Scientific and Financial:
Specifications for scientific and financial models are described and a range of models tested.

Aug.1979 Calculators:
A review of some recent models, including some for less than £10, noting the latest features available.

Sept.1979 Scientific Calculators:
The most up to date report on scientific calculators and the specifications available, including a note on programmables.

## CHAPTER 3

## MISCELLANEOUS REFERENCES

### (i) Handbooks and Manuals

Manuals or instruction leaflets produced by calculator manufacturers vary enormously in usefulness, frequently being either very brief, or far too technical for the beginner.

Of the published handbooks cited below, few will be found to be of especial value to teachers, let alone children, at this level of education.

Of those available, Jansson is by far the simplest. Benrey, Birtwistle and Texas Instruments are well worth referring to, while for those interested in something a little more detailed, Gilbert and Wyld & Bell have more to offer than most.

It is also worth noting that

Inman,D.
Calculators Computers (p.36)
contains a very clearly set out introduction to calculator use by Bob Albrecht.

S.M.P.Calculator Series:
Discover how to use your electronic calculator (p.62)
is a formal but systematic manual and

Hyatt,H.R. and Feldman,B.
The Handheld Calculator (p.34)
Is among other things, intended to be a comprehensive handbook for a variety of calculator models.

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Babani,M.H.
Electronic Calculator Users' Handbook
Babani Press 1976
Essentially a reference book for advanced applications, assuming a fair knowledge of mathematics. Some simpler algorithms are included but on the whole it is of little use at an elementary level.

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Benrey,R.M.
How to get the most out of your low cost electronic calculator
Hayden Book Co. 1976
(Distributed in U.K.by John Wiley & Sons)
An introduction to calculator use, and a handbook of general applications, aimed at a wide audience. Hardware features are well described. Calculator algorithms are discussed explicitly and at length, and are illustrated by machine-independent flow charts. Altogether, better than most books of its kind but relatively expensive.

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Birtwistle,C.
The Electronic Calculator in Business, Home and School
Elliot Right Way Books 1976

A fair general handbook, aimed in part at school use. A sizeable part of the book concerns itself with mathematics - financial calculations, mensuration, sequences/series and equation solving, treated in a clear non-technical manner.

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Bradbeer,R., and Bawtree,M.
Sinclair Book of Students' Calculations Martin Books 1979

The introduction comprises a simple, general handbook, discussing choice of calculator, scientific notation, errors and accuracy. Beyond this, much of the detailed reference material assumes a familiarity with mathematics well beyond an elementary level.

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Carter,L.R., and Huzan,E.
The Pocket Calculator (Teach Yourself Books)
Hodder and Stoughton 1979

A handbook of relatively advanced applications. However, the chapter 'Background and Principles' includes a fair treatment of specifications for Basic and Scientific calculators, operating accuracy, rounding errors and debugging errors.

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De Lisle,C.
Martin Book of Management Calculations Martin Books 1979

As the title suggests, this is a technical reference manual of little relevance to this level in education. The only 'elementary' part is Chapter 1: 'Introducing the calculator'; a very brief, general introduction.

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Gilbert,J.
Advanced Applications for Pocket Calculators Foulsham-TAB 1977

A very detailed handbook including a wide range of applications demanding a fair knowledge of mathematics. However, it also includes a useful manual for Basic Calculators, as well as a comparable introduction to the use of Scientific (including RPN - Reverse Polish Notation) and Programmable models. The book contains more general calculator algorithms than most.

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Goult,R.J., and Pratt,M.J.
The Pocket Calculator Pocket Book Stanley Thornes 1976

Essentially a handbook for the advanced user with a good knowledge of mathematics but with a general introduction covering calculator logics, scientific notation, constant functions, use of memory, chain calculations and order of operations.

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Hunter,W.L.
Getting the most out of your Electronic Calculator Foulsham-TAB 1974

This book aims to be both a handbook and a 'modern course in general and commercial mathematics'. It includes a brief description of calculator functions and a number of models formerly obtainable in the U.S.A. A limited number of algorithms are described.

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Jansson,L.
Make the most of your Pocket Calculator Foulsham 1977

A brief straightforward handbook for beginners, for both Basic and Scientific machines. Well laid out sections cover basic key sequences, use of memory, iterative methods and special functions. Exercises and a glossary of terms are included.

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King,D.
Daily Telegraph Calculator Book Daily Telegraph 1979

An edited compilation of a Saturday series on calculator use. The first section consists of a very brief introduction to using a calculator. Otherwise the book is made up of a varied collection of topics - permutations and combinations, puzzles, problems and 'real-life' applications.

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Rothery,A.
At Home with your Calculator Harrap 1980

A booklet aimed at a general audience giving an introduction to the use of a calculator principally for consumer applications.

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Shelton,J.
Calculator Mathematics Collins 1981

A general handbook for use with a basic calculator with memory. The instructions are detailed and clearly set out. Only a limited range of basic algorithms are presented.

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Texas Instruments Learning Center
Understanding Calculator Maths Texas Instruments, Dallas 1978
(Available from T.I.Technology Centres)

A wide-ranging, but rather expensive, general manual aimed at the educational user. It consists of a clear and detailed introduction to calculator use, including Scientific models, a sketch of various applications, puzzles and games, and a bibliography. It includes some interesting reference material for use at an elementary level.

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Wilson,P.A.
Your Electronic Calculator and your Money Babani Press 1979

This is not really a calculator handbook, and is certainly not aimed at children or teachers. Other than a short section on decimal notation, rounding etc., it consists almost entirely of straight commercial applications.

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Wyld,B.A., and Bell,D.A.
The Calculator Revolution: How to make the most of your calculator
White Lion 1977

While certainly not intended for teachers at this level, this is one of the more comprehensive handbooks. The summary of the history of calculating devices is useful, and much of the discussion of educational uses and future prospects is worth reading. Most of the book consists of a well-written description of 'Basic', 'Extended' and 'Advanced' calculators, including a wide range of algorithms and applications.

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(ii) Recreational

This is possibly the least well-defined category since it contains publications ranging from the purely recreational, some being the least interesting from an educational standpoint, to several written by teachers with classroom applications very much in mind.

The books referred to below are, with one exception, low-priced paperback publications.

A number of books and papers suggesting curricular materials for use with a calculator also include games and other 'recreational' material.

e.g. Blakeley,B.H.
'Calculator Corner' articles (p.49)

Leapfrogs' Action Book
Calculators (p.61)

Fisher,B.
'Calculator games: combining skills and problem solving' (p.50)

Rade,L., and Kaufman,B.A.
Adventures with your Pocket Calculator (p.54)

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Birtwistle,C.
The Calculator Puzzle Book — Elliot Right Way Books 1978

A collection of over 90 puzzles ranging from fairly easy to very difficult. Only a few are actually based on the calculator itself, but included are full solutions and explanations of how the results could be obtained by calculator.

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Boyle,P.J.
'Calculator Charades' — Mathematics Teacher, 69, 4 1976

A description of some 'calc-o-grams' (messages obtained by turning the calculator upside down). It is claimed that such activities 'help to demystify' the calculator.

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Boyle,P.J.
'Cagey calculation' — School Science and Mathematics 77, December 1977

Calc-o-grams again, briefly.

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Hamilton,B.
Calculator Fun and Games Fontana 1981
A collection of games, tricks and puzzles for use with a calculator, evidently aimed at a wide audience. The contents vary from the trivial to some activities of educational potential. The introduction consists of a brief history of calculating devices and simple user instructions.

---

Hartman,A.
The Calculator Game Book New English Library 1977
A great variety of puzzles, problems and games for Grade 4 upwards. Some indication of the mathematical concepts/skills involved is given. Some activities are calculator-based.

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Judd,W.P.
Games, Tricks and Puzzles for a Hand Calculator Dymax 1974
(available from L.P.Enterprises)
A wide range of puzzles and games including information on calculator construction and instruction on some aspects of use. There is a serious attempt to base activities on the calculator itself.

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Judd,W.P.
Games Calculators Play New English Library 1975
A very wide range of activities related to calculator use and suitable for the elementary school age range. An excellent source of ideas since many of the activities are explicitly mathematical.

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Judd,W.P.
'Instructional Games with Calculators' Arithmetic Teacher 23, 7 1976
(Minicalculators issue)
A series of calculator-based games for use in the elementary classroom.

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Jurgensen,M.
'A Calculator-Assisted Fairy Tale'
Mathematics Teacher 72, 9 1979
A rather long and involved 'calc-o-gram' puzzle.

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Rogers,J.T.
The Calculating Book — Wildwood House 1977

Described as 'a compendium of games, puzzles, puns, magic tricks, mathematical wizardry and other diversions'. The contents range from the trivial ('calc-o-grams') to a fair number of number puzzles and investigations familiar to readers of Martin Gardner's column in 'Scientific American'. Worth consulting but the activities are in no way calculator-based.

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Rothery,A.
Calculator Puzzles — Harrap 1981

A selection of games and puzzles for use with a calculator, intended for children of 9-13 years.
(Not available at time of writing)

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Schlossberg,E., and Brockman,J.
Pocket Calculator Gamebook — Corgi 1976

Fifty games and puzzles suitable for upper Juniors upwards, for use with a four-function calculator.

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Schlossberg,E., and Brockman,J.
Pocket Calculator Gamebook 2 — Corgi 1978

A further collection of fifty games and puzzles for one or more players.

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Schlossberg,E., and Brockman,J.
The Kids' Pocket Calculator Game Book — W.H.Allen (Target) 1979

A graded collection of games for upper Junior/Middle School children. An Introduction, in the form of a short manual, is followed by twenty chapters, each based on a central concept so that their use can be related to the mathematics curriculum.

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Thiagarajan,S., and Stolovitch,H.C.
Games with the Pocket Calculator — Dilithium Press 1978
(Available from Computer Research Press)

A very good, though rather expensive, collection of imaginative games to be played with the assistance of a calculator. Mental arithmetical skills are emphasised and many of the games involve practice with basic number facts plus elements of strategy and chance. A list of related magazines and books is included.

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Vine,J.
Fun and Games with your Electronic Calculator  Babani Press  1977
Originally published in the U.S.A. as 'Boggle'. The book consists entirely of 'calc-o-gram' puzzles and games, with a 'calc-o-gram dictionary'. Described as 'relaxation for the busy executive'!

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(iii) Textbooks

There have appeared in the U.S.A. over the last few years a few textbooks designed roughly for 'general mathematics' courses in High School or Two-Year College. Although on the face of it of no relevance to elementary education, some are worth referring to, at least to the extent that they have attempted to investigate the use of calculators with curriculum content that is fairly elementary.

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Chinn,W.G., Dean,R.A., and Tracewell,T.N.
Arithmetic and Calculators Freeman 1978

Described as a textbook of numerical mathematics for 'number-shy' students and adults, requiring the use of a four-function calculator. There are many references to calculator use but little calculator-based mathematics. Some of the more interesting topics, from this point of view, are Fibonacci numbers, magic squares, iterative methods and how to overcome overflow.

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Dubisch,R., and Hood,V.R.
Basic Mathematics with a Hand-Held Calculator
(With Instructor's Manual)
Benjamin/Cummings 1979

A detailed work text for general mathematics courses at high school/college level. The content covers basic arithmetic and number theory and a range of elementary practical applications, with a consideration of some problems of calculator use e.g. avoiding overflow and underflow, and rounding errors. Each chapter includes a section on games and puzzles.

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Klich,J., and Klich,C.J.
Trigonometry using calculators Addison-Wesley 1980

A textbook presenting an introductory trigonometry course, with calculator use integrated.

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Hyatt,H.R., and Feldman,B.
The Hand-Held Calculator: Use and Applications
(With Instructor's Manual)
Wiley 1979

This book is something of a hybrid manual/textbook. Assuming an 'informal' mathematical background, it aims to give instruction and practice in the use of Basic and Scientific Calculators (both algebraic logic and RPN). A fair range of mathematical content is presented, from ideas of accuracy and precision through sequences and equation solving to consumer-oriented problems. It could serve as a useful reference book though the price is high.

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## CHAPTER 4

## CALCULATORS IN THE CURRICULUM

### (i) Basic issues and prospects

The following references, in varying degrees of depth, seek to examine the curricular implications of calculator use and forecast future developments.

Blakeley,B.H.
'The Calculator Mathematics Curriculum of the Future'
IMA Bulletin 16, 8/9 1980

Perhaps the most comprehensive statement, to date, addressed to a British audience. Some of the most pertinent literature is reviewed and a range of present and future possibilities is concisely set out.

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East,P., and Mourgund,D.
Calculators and Computers in the Classroom
Oregon State Dept.of Education,Salem 1979
(ERIC: ED 174 456)

A booklet covering a wide range of information and issues. Apart from a review of the literature and a bibliography, there are sections on 'Calculators in elementary schools' and 'Problem solving with calculators'. Many suggestions for curriculum reform are made.

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Engel,A.
'The role of algorithms and computers in teaching mathematics at school'.
Chapter XIII of
New Trends in Mathematics Teaching Vol.IV
Unesco-Icmi 1978

The use of calculators is situated within the more general context of a computer-based, algorithmically-oriented mathematics curriculum of the (near?) future. While including many practical suggestions, Engel offers the most revolutionary view of the role of computing machinery in future curricula. A new reform, in favour of 'algorithmic thinking' is urged. Many examples of basic algorithms, and many references, are given.

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Gawronski,J.D., and Coblentz,D.
'Calculators and the mathematics curriculum'
Arithmetic Teacher 23, 7 1976
(Minicalculators issue)

The authors attempt an overall view of the implications of calculator use. 'Functional' and 'pedagogical' views of the curriculum are contrasted and the importance of problems emphasised at the expense of much routine computation. It is stressed that the nature and role of 'basic skills' needs to be re-examined.

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Henry,L.L.
'Invaluable aid to understanding mathematics: the hand-held calculator'.
School Science and Maths 77, Nov.1977

The view is taken that, far from threatening the development of basic skills, use of calculators can enrich the quality and increase the quantity of mathematics learning, by concentrating on mathematical concepts and processes and minimising routine calculation.

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Inman,D.(ed.)
Calculators Computers - a source book of activities
Addison-Wesley 1978

A compilation of articles from the first few issues of the magazine 'Calculators/Computers'. A very wide range of uses for computing machinery is indicated - articles by David Moursund, Jean Rogers and Bob Albrecht deal specifically with calculators. The latter are seen as agents of urgently needed change in mathematics curricula.

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Johnson,D.C.
'Calculators: Uses and Abuses'
Mathematics Teaching 85 1978

Johnson spells out, in considerable detail, not only current 'abuses' of calculators in the classroom, but also what are seen as their most fruitful uses now and in the future. These uses are categorised and exemplified.

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Pollak,H.D.
'Hand-held calculators and potential re-design of the school mathematics curriculum'.
Mathematics Teacher 70, 4 1977
{Appendix D of Suydam,M.N.(ed.) 'Electronic Hand Calculators: The Implications for pre-College Education' 1976(p.2)}

The most important question is identified as being 'what are some of the most difficult problems we have in teaching school mathematics with which the calculator might help?' Some such problems are identified. Two partial orderings of the curriculum are described - mathematical and societal - and the effects of calculator use on both considered.

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Schmaltz,R.
'Calculators, what difference will they make?'
Arithmetic Teacher 26, 4 1978

Possible attitudes to calculator use are discussed and the judgment made that it should be integrated into the curriculum at all levels. The calculator is seen as forcing a revolution in our attitude to computation and to the algorithms conventionally taught.

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Stultz,L.
'Electronic calculators in the classroom'
Arithmetic Teacher 22, 2 1975

Although a little dated now, this paper looks forward to a wide range of classroom applications for calculators and consequent curricular changes.

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Teitelbaum,E.
'Calculators for classroom use?'
Arithmetic Teacher 26, 3 1978

A distinction is drawn between computational skills and applications. It is foreseen that use of calculators should provide more time to develop skills in problem solving rather than rote computation.

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Watson,F.R.
'Calculators: Promising Practices in the Teaching of Mathematics (including current and needed research)'.
IMA Bulletin 16 8/9 1980

A very broad, detailed and up to date account of the best current ideas and materials. Included are notes on research problems.

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Wheatley,G.H.
Calculators in the Classroom: A Proposal for Curricular Change
Paper presented to American Educational Research Association Conference (AERA), San Francisco 1979.
(ERIC: ED 175 631)

The effects of calculator availability on the elementary mathematics curriculum is considered in depth. The use of the calculator as an instructional tool is emphasised and it is proposed that there should be a significant shift from a computationally based to a conceptually based curriculum.

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Wheatley,G.H.
'Calculators in the Classroom: a Proposal for Curricular Change'
Arithmetic Teacher 28, 4 1980

A shortened version of the previous reference.

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(ii) General surveys

From time to time, writers have, in varying degrees of detail, attempted to identify the areas of the mathematics curriculum which would be most affected by calculator use.

Averett,D.M. et al
Using the minicalculator to teach mathematics

Office of Curriculum and Instruction, Philadelphia School District, Pa 1977 (ERIC:ED 141 126)

A well-illustrated booklet offering detailed suggestions and directions to teachers at elementary and secondary levels. A very wide range of content is indicated, and illustrated by rather formal exercises. For each topic background information is supplied, with sample activities, games and problems. There is also a section on choosing a minicalculator, and a select bibliography.

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Beardslee,E.C.
'Teaching computational skills with a calculator' in Suydam,M.N.(ed.)
Developing Computational Skills

Yearbook N.C.T.M. 1978

The possible effects of calculator use on traditional arithmetic teaching are considered. The motivating power of calculators is noted and a fair number of calculator assisted activities are described in detail, e.g. counting, reading numbers, place value, operations, problem solving, pattern investigation and decimals.

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Brumi,J.V., and Silverman,H.J.
'Taking advantage of the hand calculator'

Arithmetic Teacher 23, 7 1976

(Minicalculators issue)

One of the best of the earlier compendia of suggestions for elementary school teachers. The content ranges over play, analysis of algorithms, estimation and mental calculation, word problems and practical activities. A number of quite specific classroom activities are described.

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Krist,B.J.
Uses of Calculators in Secondary Mathematics

Information Bulletin no.8
Calculator Information Center,
Columbus, Ohio Sept.1980

A brief description of areas of the curriculum in which calculators can be used, including sequences, series, limits and investigations of some of the 'scientific' functions themselves.

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Maor,E.
'A Summer Course with the TI 57 Programmable Calculator'
Mathematics Teacher 73, 2 1980

A report on a supplementary mathematics course undertaken with high-potential children, including one group of Elementary/Junior High school age. Apart from a discussion of the suitability of the calculator specifications, the very wide range of work attempted is described.

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Morris,J.P.
'Problem Solving with Calculators'
Arithmetic Teacher 25, 7 1978

A fairly general discussion of the possible classroom applications of a 4-function calculator. Emphasis is placed on problem solving technique, e.g. 'guess and check', and on individual exploration.

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Mourmund,D., and East,P.
Calculators and Computers in the Classroom: Select Summaries of Current Educational Topics
Know - Pak no.17
Oregon State Dept.of Education 1979
(ERIC:ED 191 710)

One of a series of information pamphlets which includes calculator and computer terminology, calculator use in elementary schools, available textbooks, sample problems and bibliographies.

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Ockenga,E.
'Calculator ideas for the junior high classroom'
Arithmetic Teacher 23, 7 1976
(Minicalculators issue)

Many practical examples of classroom activities are given ranging from those involving numerical skills to applications and calculator-based problems.

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Shoen,H.L.
Calculators in Mathematics - How they should be used.
Paper presented at American Educational Research Association (AERA) Conference, San Francisco 1979.
(ERIC: ED 175 628)

A brief but well-illustrated account of practical activities with a basic calculator for grades 2-6. Topics covered include counting, numeration, estimation and problem solving.

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Stephens,M.
'Developing classroom materials utilising minicalculators'.
Australian Mathematics Teacher 34, 5 1978

The problems of calculator use are discussed, and also the possible constraints on mathematics teaching. Some of the features of calculator assisted and calculator based curricula are described, with examples, and speculations made about future curriculum developments.

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(iii) Numeracy

Widespread use of pocket calculators in the near future, both in and out of the classroom, has profound implications for the teaching of numerical concepts and skills in elementary education. Definitions of numeracy inevitably change along with economic and cultural transformations and the perceived needs of society.

Several writers have addressed themselves to these issues and have speculated about the basic skills needed in the late twentieth century.

Girling,M.S.
'Towards a definition of numeracy'
Mathematics Teaching 81 1977

A thoughtful and provocative attempt to redefine numeracy, namely, '....the ability to use a four-function electronic calculator sensibly'. This proposal is spelled out in some detail.

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Hersee,J.
'Numeracy-towards a definition'
Mathematics in School, 7, 4 1978

A very wide-ranging discussion of numeracy and related issues. The provisional definition stated is very broad and it is suggested that such basic skills may only make any real sense within the broader context of mathematical education.

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Hiatt,A.A.
'Basic skills: what are they?'
Mathematics Teacher 72, 2 1979

It is emphasised that 'basic skills' make little sense treated in isolation but only in wider mathematical context, and especially the 'process' skills which might be aided by the use of calculators. A variety of numerical investigations are suggested.

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Johnson,D.C.
Figures and Chips (see p.8)

The standpoint adopted by Girling (see above) is developed and discussed in a wider context.

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N.C.S.M. (National Council of Supervisors of Mathematics)
'Position paper on basic mathematical skills'
Mathematics Teacher 71, 2 1978

Any narrow definition of basic skills is deplored and the expanded definition given covers ten 'vital areas', by no means all numerical. It is recognised that much complicated computation will, in future, be done by calculator. This statement, as a whole, appears to have had considerable influence since among mathematics educators.

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N.C.T.M. Editorial Panel
'Computational skill is passé'.

Mathematics Teacher 67, 6 1974

{reprinted in Neufeld,K.A.(p.15)}

An early survey of teachers, mathematicians and laymen is reported. Seven questions concerned with the future of 'basic skills' and the use of calculators, and the responses to them, are described in detail.

---

Plunkett,S.
'Decomposition and all that rot'.

Mathematics in School 8, 3 1979

A contrast is drawn between the idiosyncratic methods of calculating used by children and the uniformity of the 'standard written algorithms' conventionally taught in school. The latter are criticised as generally inappropriate and misused. It is proposed that priority be accorded to mental techniques, supplemented by the use of calculators for larger numbers, with 'casual written methods' being used last of all.

---

Sturgess,D.
'What Should They Know at Sixteen?'

Mathematics Teaching 85 1979

The basic minimum of mathematics required by the age of 16 is considered and adjudged to consist of a set of very simple skills. A high priority among these is seen as being how to use a calculator with confidence and efficiency.

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47

(iv) Fractions vs. Decimals

The prospect of extensive use of calculators in schools has provoked even more controversy over the future role of fractions in school mathematics. The issues are far from resolved and the following references convey something of the spirit and content of the debate.

Cable,J.
'A Society for the Preservation of Fractions'
Mathematics in School 5, 4 1976

A range of reasons is presented for the continuing importance of fractions.

---

Joy,R.R.
'In defence of fractions'
Mathematics in School 5, 4 1976

The retention of much work on fractions is justified on the grounds that it is necessary for an understanding of decimals. It is claimed that methods of teaching fractions need to be reconsidered.

---

Kidder,F.R.
'Ditton's Dilemma; or What to do About Decimals'.
Arithmetic Teacher 28, 2 1980

It is proposed that, because of the problems raised by calculator displays, decimals should be taught earlier, and independently of operations on fractions. An appropriate instructional programme is outlined.

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Lloyd,D.G.H.
'The case against fractions'
Mathematics in School 5, 2 1976

The claim is made that fractions are no longer an appropriate part of the curriculum for children of 5-13 years, and that the time saved should be given to more fundamental numerical work. The rationale for this is discussed in detail.

---

Payne,J.N.
'Sense and nonsense about fractions and decimals'
Arithmetic Teacher 27, 5 1979

The whole controversy over fractions and decimals is reviewed. While it is conceded that decimals will have to be introduced earlier the contrast fractions/decimals is rejected as over-simplified. It is further suggested that there is a pressing need for analysis and research on instructional strategies for the teaching of decimals.

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Sawyer,W.W.
'The case for fractions'
Mathematics in School 6, 1 1977

A consideration of the extent to which work on fractions could be reduced. The view is expressed that the crucial task is to make fractions more interesting and comprehensible.

---

Usiskin, Z.P.
'The Future of Fractions'

Arithmetic Teacher 26, 5 1978

A detailed discussion of some fundamental issues concerning fractions and decimals. Doubts are cast on the claim that calculator use will result in a diminished role for fractions. The usual statement of the controversy is dismissed as simplistic and the challenge of calculator use is characterised as being a matter of what to do rather than how.

---

(v) Estimation and accuracy

The point is made by many writers {e.g. Johnson(p.8), Girling(p.40)} that skill in estimating the size of results should be an essential component) in a contemporary definition of numeracy, especially if calculators are to be used freely from an early age. Also the use of an 8-digit calculator will inevitably raise the issues of precision, accuracy and errors.

Hirst,K.et al
'Significant Figures'
Mathematics in School 9, 5 1980

A collection of 3 articles
1) Hirst,K.
'Numbers, significance and calculators'
2) Easingwood,T.
'More about significance'
3) Webb,M.
'How many significant figures?'
{see Webb 1980(p.45)}

The issues of significant figures are discussed in some detail and the articles are relevant, at least in part, to the Middle/Lower Secondary school.

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Hersee,J.
'Yet more sig.figs..'
S.M.P.News 15 1981
(in Times Ed.Suppl. 20 March)

A collation of and final comment on the views of Webb and Wynne Willson in the other references on the same subject in this section.

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Johnson,D.C.
'Teaching estimation and reasonableness of results'
Arithmetic Teacher 27, 1 1979

Deficiencies in current practice of teaching 'reasonableness' and estimation are indicated and some possible strategies for teaching estimation are outlined, starting from single digit arithmetic and the ability to work with powers of ten. It is suggested that 'reasonableness' depends on the context - a physical reality, or a mathematical one. The article is notable for its assertion that such ideas can be taught more or less explicitly.

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Mustoe,L.R.
'2 + 2 = 3.99'
Mathematics in School 5, 5 1976

The problem of interpreting results in calculator displays is discussed in some detail, including consideration of truncation/rounding off, accuracy and errors.

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Ockenga,E., and Duea,J.
'Use of hand-held calculator to provide practice in estimation'
Arithmetic Teacher 26, 5 1978

A series of games for elementary/junior high school children is described.

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Ockenga,E., and Duea,J.
'Use a hand-held calculator to provide practice in estimation'
Arithmetic Teacher 26, 8 1978

Another series of activities is described, extended to use of decimal numbers.

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Webb,N.
'How many sig.figs.?'
SMP News 13, Summer 1980

The frequent confusion about the criteria for deciding on the number of significant figures is discussed. Some conventions and notation are suggested which might help to clarify the situation.

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Wynne Willson,W.
'More sig.figs.'
SMP News 14, November 1980

A critical response to the suggestions made by Webb (above).

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(vi) Recurring decimals

The investigation of recurring decimals has been seized on by a number of writers as an 'obvious' calculator-assisted activity. Both the British and American teaching journals have published a number of articles recommending such activities for the classroom. While not all of these make specific mention of calculators, investigation of the topic at an elementary level would, for most children, require their use.

In particular, a number of articles in Mathematics Teaching referred to below might usefully be read in chronological order.

Balderstone,B.
'Recurring decimals again'
Mathematics Teaching 79 1977
A brief note commenting on Beldon (see below).

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Beldon,T.
'Recurring decimals'
Mathematics Teaching 70 1975
An investigation of the cyclic structure of recurring decimals with 12-13 year olds, with no mention of calculator assistance.

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Hobbs,B.F., and Burris,C.H.
'Minicalculators and repeating decimals'
Arithmetic Teacher 25, 7 1978
An algorithm is developed for expressing fractions as decimal expansions to n digits and the cyclic patterns produced are investigated.

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Lichtenberg,D.R.
'Minicalculators and recurring decimals'
Mathematics Teacher 71, 6 1978
It is suggested that the use of a calculator (8-digit, truncating display) would enable younger students to investigate the topic profitably. An informative though very formal account, to be compared with Watson 1976 (see below).

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Ounstead,J.
'Pocket calculators and recurring decimals'
Mathematics Teaching 82 1978
The use of an 8-digit display calculator is recommended for finding recurring decimal expressions. The search for more efficient algorithms (using a smaller number of key closures) is described.

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Pallister,J.
'Recurring decimals - yet another algorithm'
Mathematics Teaching 83 1978
A calculator algorithm is described for finding recurring decimals.

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Turnbull,A.et al
'Still more on recurring decimals'
Mathematics Teaching 80 1977
Three brief articles in the 'Topics' section:
1) Turnbull,A., Weatherley,J., Harvey,R., and Pallister,J.
An investigation, with a calculator, of decimal expansions of fractions of the form $1/n$ where n is prime and $n > 5$.
2) Pallister,J.
A similar investigation is described with children.
3) Tyler,K.
A note on an investigation by 11-year-olds of recurring digits in the expansions of sevenths, ninths, elevenths, etc.

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Wagner,S.S.
'Fun with repeating decimals'
Mathematics Teacher 72, 3 1979
While not mentioning calculators, this is a thorough account of the topic and one of the best of a number of articles in the same journal.

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Watson,F.R.
'Finding out about recurring decimals'
Mathematics in School 5, 2 1976
An investigation, guided by a sequence of questions, is outlined, giving a fuller and more comprehensive treatment than the other references cited here. {see also Watson 1979 (p.63)}.

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Wilson,G.M.
'More recurring decimals'
Mathematics Teaching 75 1976
An account of an investigation by children of fractions with prime denominator - the resulting patterns are represented graphically.

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(vii) Calculators in Special Education

A number of articles in this category have appeared in American journals not readily available in the U.K.

The following references are the only ones that have proved to be easily accessible.

Bailey,J.F.
'Electronic Calculators and the Multiply Handicapped'
Educational Research 23, 1 1980

A brief note on the introduction of calculators to handicapped children. Scores improved noticeably and the children were motivated to attempt far more than previously.

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Ideas for Strengthening Math Skills

New York State Education Dept. 1978
and Bureau of Gen.Educ.Curric.Devt.,
State University of New York, Albany.
(ERIC:ED 161 730)

A compendium of specific approaches to remedial mathematics including a section on 'the calculator in remedial mathematics'. This includes a variety of well-illustrated number activities and some simple problems.

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Stolovich,H.
'Pocket calculator never loses patience'
Audio-Visual Instruction 21, 10 1976

This includes a full discussion of the value of the pocket calculator in the education of the handicapped with a brief outline of specific uses.

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(viii) General

The British and American teaching journals have carried a considerable number of articles discussing particular aspects of calculator use in the mathematics curriculum or, in some cases, quite specific activities.

There is also an even more extensive literature on mathematical investigations, many of which are obvious candidates for calculator assistance, although a survey of this would go far beyond the immediate concerns of the present work.

Blakeley,B.H.
'Calculator Corner' Mathematics in School 8, 2; 8, 4; 8, 5; 9, 1; 9, 2; 9, 3. 1979-80

A series of short articles describing a range of elementary games and investigations for use with a basic calculator.

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Bolduc,E.J.
'Using a minicalculator to find an approximate value for $\pi$'
School Science and Maths 77, Dec.1977

A short description of the development, from the Archimedean approach, of an iterative formula for evaluating $\pi$.

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Casio Electronics
'A square root algorithm'
Mathematics Teaching 79 1977

One particular calculator algorithm for finding square roots is set out in detail.

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Channell,D.E.
'Using Calculators to Fill Your Table'
Mathematics Teacher 74, 3 1981

The construction, with calculator assistance, of tables of values of functions is described, along with their use in the solution of maximisation problems relating to, for example, perimeters and areas.

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Dorn,C., and Councilman,S.
'Some properties of the calculator square root function'
Mathematics Teacher 73, 3 1980

A relatively advanced discussion of functions and limits but relevant in part to younger secondary school children.

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Duea,J., Immerzeel,G., Ockenga,E., and Tarr,J.
'Problem Solving using the Calculator'
in
Krulik,S.(ed.)
Problem Solving in School Mathematics
Yearbook N.C.T.M. 1980

A strategy is described for solving a fairly restricted range of word problems by coding them by means of calculator key sequences. A number of sample workcards is included.

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DuRapau,V.J., and Bernard,J.
'From Games to Mathematical Concepts via the Hand-held Programmable Calculator'
Int.J.Math.Ed.Sci.Technol. 10, Jul./Sept. 1979

The (programmable) calculator is considered to be essentially a 'function machine' and a valuable means of introducing many mathematical concepts earlier than before. The calculator's role in the development of proofs, even at 'upper elementary' level, is proposed and a 'theorem proving game' is outlined.

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East,P. and Moursund,D.
Calculators and Computers in the Classroom (see p.35) 1979

This booklet also includes specific examples of teaching materials, notably activities exploring the mathematics of the calculator itself.

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Eimer,R.A.
'Cube roots on a calculator'
Mathematics Teacher 70, 2 1977

A brief account of a calculator algorithm for finding cube roots.

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Ercolano,J.
'Fraction computations on a calculator'
Mathematics Teacher 72, 8 1979

A way of handling fractions by discussion is described and the need for coping with a truncating display noted.

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Fielker,D.S.
'Using Electronic Calculators'
Mathematics Teaching 76 1976
{reprinted in Neufeld,K.A.(p.15)}

An informal report of a calculator experiment in a London secondary school. Reactions to calculators and the range of classroom activities attempted are described, including details of topics.

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Fisher,B.
'Calculator games: combining skills and problem solving'.
Arithmetic Teacher 27, 4 1979

Two games and an activity for the elementary school, involving problem solving and a review of basic facts.

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Friedlander,R.J.
'Efficient algorithms for the calculator'
Mathematics Teacher 71, 7 1978

A rather advanced treatment of the design of calculator algorithms e.g. for addition of fractions. The need to learn to use the calculator in the most efficient manner is stressed.

---

Green,D.R., and Lewis,J.
Science with Pocket Calculators (see p.18)
Wykeham 1978

Although evidently intended for the upper secondary school and for users of more advanced calculators, the case studies in science and mathematics include some fairly elementary applications.

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Haigh,G.
'Number Bases, Calculators and Geometric Progressions'
Mathematics in School 10, 2 1981

A short account of a possible investigation which would benefit from calculator assistance.

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Hale,D.S.
'Using Electronic Calculators'
Mathematics Teaching 67 1974

An early note on the use of calculators describing two optimisation problems and the role, in their solution, of the testing of conjectures and finding successive approximations.

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Hemming,R.
'Handling numbers'
Mathematics Teaching 48 1969

A description of a number investigation - originally intended for a mechanical calculator.

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Johnsonbaugh,R.
'Applications of calculators and computers to limits'
Mathematics Teacher 69, 1 1976

A rather advanced treatment but containing observations of wider significance. A numerical approach to analytical concepts is proposed on the grounds that numbers are 'more real' than symbols. The calculator is seen as a 'motivating, essential device, integrated with the theory'.

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Johnson,D.C.
'Calculator Exploration for Concept Reinforcement'
Mathematics Teaching 95 1981

This brief article comprises a set of exercises for use with a calculator intended for practice and application of concepts and relationships already studied, namely, single-digit basic facts, inverse operations, place value, and estimation of the relative impact of operations on whole numbers.

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Johnson,H.C., and Moyer,J.C.
'Some elementary number theory concepts performed on the hand calculator'
Int.J.Math.Ed.Sci.Technol.12, 2 1981

The use of a calculator (an 'extended basic' version suitable for junior high school) is recommended for exploring some aspects of number theory. A number of appropriate problems are described.

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Keller,C.
'Using tables to teach mathematics'
Mathematics Teacher 71, 3 1978

It is proposed that the calculator be used, in group activities, to construct tables, including simple ones such as factors, squares, cubes etc. Such tables could then serve as the raw material for investigations.

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Lappan,G., and Winter,M.J.
'A calculator activity that teaches mathematics'
Arithmetic Teacher 25, 7 1978

A detailed description of a classroom activity (a variation of Bingo) for grades 3-5 involving products. The activity entails the search for successful strategies, estimation and rounding. Extensions for older and younger children are suggested.

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Lappan,G., and Winter,M.J.
'It's what you do first that counts....'
School Science & Maths 79 May/June 1979

An account of a sequence of activities for upper elementary school children beginning with an exploration of the order of operations.

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Leutzinger,L.P., and Nelson,G.
'Let's Do It With Powers of Ten'
Arithmetic Teacher 27, 6 1980

A scheme of activities for developing competence in handling powers of ten is described. The use of a calculator is mentioned as one of the activities.

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Lichtenberg,B.K.
'Calculators for kids who can't calculate'
School Science and Maths 81 Feb.1981

A variety of calculator-assisted and calculator-based activities are recommended for children who are generally lacking in competence in basic arithmetical skills.

---

Litwillier,B.H., and Duncan,D.R.
'Calculations you would never make without a calculator'
Mathematics Teacher 70, 8 1977

A lot of examples are given of calculations which could be done with a calculator, varying from problems involving large numbers and the processing of statistical data to a number of trivial ones which may or may not amuse children.

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McGinty,R.L., and Eisenberg,T.A.
'Palindromic numbers can liven up your classroom'
School Science and Maths 78
May/June 1978

A full account of a number investigation, suitable for even quite young children, which, on account of the volume of number processing involved, is ideally calculator assisted.

---

Maor,E.
'Some uses of the exchange key on a calculator'
Mathematics Teacher 73, 3 1980

Various uses for the x ↔ y and x ↔ m keys are suggested e.g. Fibonacci numbers and geometric series.

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Michelow,J.S., and Vogeli,B.R.
'New world of calculator functions'
School Science and Maths 78 Mar.1978

The importance of the function as a unifying concept in mathematics is stressed and the possibility suggested of a function-based curriculum. The calculator (scientific) is seen as the generator of a whole range of unary and binary functions which may be investigated, including composites and inverses. The treatment is formal and advanced but the material is relevant to elementary work.

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Millar,W.A., and Hazekamp,D.W.
'Calculator graphing'
Mathematics Teacher 71, 9 1978

Some specific examples are given of activities for grades 7-12 on graphing functions, involving using a calculator and rounding.

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Nicolai,N.B.
'Sum of the Integers'
Mathematics Teacher 71, 4 1978

The uses of a calculator at junior high school level for number investigations is described, along with one particular investigation in number theory.

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Olson,M.
'Using calculators to stimulate conjectives and algebraic proofs'.
Mathematics Teacher 72, 4 1979

A brief but lucid discussion of the use of calculators in determining patterns and making conjectives from a relatively large number of numerical examples.

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Open University
PME 233 Mathematics across the Curriculum
(see review in Mathematics in School 9, 4 1980.)

Part of this novel course in mathematics education is inspired by the USMES project. It includes a series of notes on calculator use.
{see Shields(p.55)}

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Padberg,F.F.
'Using Calculators to Discover Simple Theorems - an Example from Number Theory'
Arithmetic Teacher 28, 8 1981

A simple numerical investigation, suitable for use in elementary school, is described in some detail.

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Pagni,D.L.
'Number theory for secondary classes'
Mathematics Teacher 72, 1 1979

A very formal proposal for the use of calculators to aid, for example, prime factorisation.

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Rade,L., and Kaufman,B.A.
Adventures with your Pocket Calculator
Penguin 1980

A particularly good collection of activities with a basic calculator at, roughly, high school level, although much of it is adaptable for younger children. The book is divided into two parts:
'Adventures' - problems and activities inviting the reader to make conjectures and test them.
'Commentaries' - full discussions of the problems with a range of extensions.

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Riden,C.
'Less than ten on a calculator: use an adding machine to check addition and subtraction problems in number bases less than ten'.
School Science and Maths 75 Oct. 1975
Description of some uses of a simple adding machine. A straightforward presentation of some algorithms.

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Schmaltz,R.
'Calculator Capers'
Mathematics Teacher 71, 5 1978
(Calculators/Computers issue)
Several worksheets presenting patterns of products for making predictions and conjectures.

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Schultz,J.E.
'Using a calculator to do arithmetic in bases other than 10'
Arithmetic Teacher 26, 1 1978
A simple description of some particular uses of a calculator which may lead to a firmer understanding of place value.

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Schultz,J.E.
'How calculators give rise to a new need for skills in algebra'
School Science and Maths 78 Feb.1978
Effective use of a calculator is claimed to demand a variety of manipulative techniques, so that certain algebraic manipulations need to be learned prior to using a calculator, in order to e.g. eliminate unnecessary storage, reduce the number of steps and avoid overflow.

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Sharron,S.(ed.)
Applications in School Mathematics
Yearbook N.C.T.M. 1979
A collection of papers of general interest for applications throughout school mathematics, including a chapter on financial calculations with a calculator, and an annotated bibliography.

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Shields,J.J.
'Minicalculators and Problem Solving'
School Science and Maths 80, Mar.1980
A general discussion of the role of calculators in education with the suggestion of a major application in 'problem solving'. Using a model based on Information Theory, the teaching of problem solving is considered in detail, with related use of calculators. Reference is made to the USMES (Unified Science and Maths. for Elementary Schools) project.

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Slayer,C.W.
'Geometric growth and the hand-held calculator'
Mathematics Teacher 73, 8 1980

A detailed description of an investigation carried out at secondary school level involving the observation of patterns, making conjectures, mathematical induction etc.. The real challenge is said to be: 'how can we teach more and better mathematics with the use of a calculator?'.

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Smith,S.
'Calculating order'
Mathematics Teacher 71, 6 1978

Some examples of work designed to develop and reinforce the concept of order of operations at high school level.

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Smith,S.M.
'Calculating Algebra'
Mathematics Teacher 74, 2 1981

A calculator activity concerned with linear equations with integer coefficients is described. The scheme of work, including a game, is claimed to involve mental computation and estimation.

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Snover,S.L., and Spikell,M.A.
'Role of programmable calculators and computers in mathematical proofs'.
Mathematics Teacher 71, 9 1978

Relating to a quite advanced level, examples are given of problems for solution with the aid of a calculator or computer, testing conjectives and designing algorithms.

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Stone,J.S.
'Powers have patterns'
Arithmetic Teacher 25, 1 1977

Some very practical activities, intended for grade 7, on number patterns, for use with a calculator.

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Teitelbaum,E.
'Calculators for classroom use' (see p.37) 1978

This paper includes several examples of classroom applications e.g. area, time, distance and speed.

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Turinese,D.M.
'Approximations to Pi using a calculator'
Mathematics Teaching 89 1979

A short account of historic iterative procedures, all translatable into calculator algorithms, from Archimedes to Leibniz.

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Watson,F.R.
'Triangular Squares'

Mathematics Teaching 85, 86, 87 1978

A three-part discussion of a calculator-assisted investigation in number theory.

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Weaver,J.F.
Calculators and Unary Operations: A position paper with instructional suggestions

(Project Paper 77-7)
R & D Center for Cognitive Learning,
Univ.of Wisconsin, Madison 1977
(ERIC:ED 161 672)

This paper, one of a series from the University of Wisconsin, gives a number of suggestions for teaching materials e.g. relations, inverses, commutativity, distributivity and iterative procedures, with discussion of appropriate calculator algorithms.

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Weaver,J.F.
'Calculators and Unary Operations'

School Science and Maths 81, April 1981

A brief account of some general issues arising from research conducted at the University of Wisconsin and reported elsewhere (p.74).

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Wheatley,C.L.
'Calculator Use in the Middle Grades'

School Science and Maths 80, Nov.1980

The motivating power of the calculator is considered, along with the promise of overcoming computational barriers. Four activities which 'capitalise on the calculator as an instructional aid' are described: estimating sums/addends, problem solving, making comparisons and decimals.

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Williams,D.E.
'The Language of Calculators'

Arithmetic Teacher 28, 5 1981

The assumption that a calculator can be used effectively with no formal instruction is rejected. There follows an elementary but detailed account of what is involved in coping with the calculator's 'logic', including the design of algorithms and the search for more elegant ones.

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Wynne Willson,W.
'Fractions by calculator'

Mathematics in School 7, 3 1978

A detailed exploration of the problem of converting decimals to fractions in their lowest terms using a calculator. A general method is expounded, along with a detailed algorithm.

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(ix) Using calculators in the classroom

Only a very small part of the literature so far consists of direct reportage of work with children. Many references elsewhere in this chapter refer to work done in schools but are mostly indirect accounts, often emphasising the results rather than the activity.

Reports of some curriculum projects include references to the actual responses of children to calculators, notably

Bell,A.W. et al
A Calculator Experiment in a Primary School
(p.72)

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Aidala,G.
'Calculators: their use in the classroom'
School Science and Maths 78, April 1978

A general report of work with calculators in the 8th grade of an American inner-city school. The aims and details of administration are given; use was tightly controlled and calculators were used strictly for supplementary work over the four year period. The work attempted is described in outline.

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Aidala,G., and Rosenfeld,P.
'Calculators in the classroom'
Mathematics Teacher 71, 5 1978
(Calculators/Computers issue)

A shortened version of Aidala,G. 1978 (above)

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Barrett,R., and Keefe,M.
Using hand-held calculators in 6th grade classes:
A brief report of an educational project.
New York State Education Dept., Albany and Bureau of Math.Education, State University of New York, Albany. 1974
(ERIC:ED 142 410)

A brief report of an exploratory pilot project in two schools over a period of one year. Apart from a description of the administration of the project some indication is given of the range of work done and the students' reactions.

---

Davies,B.
'Using Calculators with Juniors'
Mathematics Teaching 93 1980

A detailed report on experimental work with Junior school children - games, problem solving and handling large numbers. Decimal numbers were inevitably encountered early on and calculator use recognised as of value in revealing degree of understanding and providing a basis for investigational work.

---

Fielker,D.S.
'Using Electronic Calculators'
Mathematics Teaching 76 1976
{reprinted in Neufeld,K.A.(p.15)}
An informal report of experimental calculator use in a London Secondary school. Apart from a report on the range of work, reactions to calculators and some description of classroom experience is included.

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Hutton,L.A.
'Calculators, Teachers' Attitudes and Children's Ability'
Mathematics Teaching 90 1980
A brief report of a one year calculator project in the Indianapolis Public schools with children in grades 4, 5 and 6. The teachers' attitudes and reactions to the experiment are described in some detail.

---

Jones,C.
'72 x 49'
Mathematics Teaching 94 1981
A brief account of an exploration, with primary school children, of the multiplication algorithm. The'catalytic presence of the calculator' is remarked upon in the generation of ideas and alternative procedures.

---

Knowles,F.
'Coloured rods, a calculator and decimals'
Mathematics Teaching 86 1978
(Primary Supplement)
A detailed discussion of work done in a Primary school using calculators alongside coloured rods. Work with decimals and very small fractions was developed and calculators seen as a natural way into decimals, through division of integers.

---

Meyer,P.I.
'When you use a calculator, you have to think'
Arithmetic Teacher 27, 5 1980
Work with grade 4 children is described briefly. The children appear to have engaged in much exploratory work with calculators, although few details are given. 'Real' problem solving was seen to be the most valuable activity, involving reasoning and basic numerical skills.

---

Russell,S.
'Calculators in the Classroom'
Mathematics Teaching 78 1977
A wide-ranging discussion of exploratory work attempted with secondary school pupils of low ability. The range of work attempted is indicated.

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Sullivan,J.L.
'Using hand-held calculators in sixth grade classes'
Arithmetic Teacher 23, 7 1976

An early account of work undertaken with young children. A variety of work was attempted, in particular, decimal fractions.

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Vannatta,G.D., and Hutton,L.A.
'A case for the calculator'
Arithmetic Teacher 27, 9 1980

An alternative report of the Indianapolis project {see Hutton(p.59)}.

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Zakariya,N. et al
'The Calculator in the Classroom'
Arithmetic Teacher 27, 7 1980

Three examples are given of weekly calculator lessons with upper elementary school children. The work was made more challenging and went beyond the conventional curriculum.

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(x) Curriculum materials

Over the last few years a number of publications (books and multi-media kits) intended for schoolchildren in Elementary and Junior High Schools have appeared in the United States. Some of these are now, at least nominally, available in the U.K.

Those known are included in the following list, along with the limited number of publications so far produced in this country.

Humphreys,C. et al
Calculator Cookery

Minneapolis Public Schools 1977
(ERIC:ED 146 009)

A varied collection of material produced by teachers for use in Grades 9-10 in general mathematics courses - use of the calculator, games, exploring patterns and algorithms, estimation and consumer applications. It also includes an annotated list of references. Much of the material is suitable for younger children.

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Immerzeel,G., and Ockenga,E.
The Calculator Books 1 and 2

Addison-Wesley 1980

(with Teachers' Books)

A varied collection of classroom material aimed particularly at the junior high/lower secondary school age range.
(see other references to the same authors and to the Univ.of Northern Iowa Problem Solving Project).

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Judd,W.P.
Using your Calculator

S.R.A. 1980

A consumable workbook for ages 11-17 aimed at familiarisation with the features and uses of the pocket calculator.
(not available at time of writing).

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Judd,W.P.
Problem Solving Kit

S.R.A. 1980

A boxed collection of pupils' materials, with a Teachers' Guide, which aims to teach problem solving. Areas of application are: averages, percentages, rates, ratio and proportion, combinations, finite differences and sequential ratios.
(not available at time of writing).

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Leapfrogs
Calculators (Action Book) 1977

A short but concentrated booklet of starting points for activities, games and problems for approximately the 10-13 age range. Brief but very practical.

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Getting to know the calculator; Problem Solving Project
Mathematics Learning Center,
Univ.of Northern Iowa 1975
(ERIC: ED 161 757)

A collection of activities for elementary/junior high schools are presented - pattern recognition, combination of operations, estimation, squares/square roots, rate problems, area and volume.

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Calculator Handbook; Problem Solving Project
Mathematics Learning Center,
Univ. of Northern Iowa 1975
(ERIC: ED 161 758)

Similar material to that in the reference above; a collection of student worksheets on natural number arithmetic, number patterns, volume, inequalities, decimal equivalents of fractions and percentages.

---

Rothery,A.
Calculator Maths
Harrap 1980

Aimed at 12 years and upwards, and intended to be supplementary to the normal curriculum, this book introduces the calculator as an aid to problem solving. A wide range of subject matter is covered, including games.

---

School Mathematics Project
SMP Calculator Series:
5 booklets:
Discover how to use your electronic calculator
Sequences and Iterative Processes
Growth and Decay
Calculator Supplement to Books X, Y, Z
Calculator Supplement by Topics
and
Teachers' Guide C.U.P. 1979

This series of booklets was designed 'for students following 'O' level course alternative C in the early stages of its existence' and was not intended to be a permanent part of the 'O' level course. Nevertheless, the first three booklets provide an interesting source of material for use with younger or less able children.

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SMP (School Mathematics Project)
Compack materials C.U.P. 1976
('Computer Orientated Mathematics Package')

Several packs of workcards, with a teachers' booklet and introductory materials, designed as a resource bank of materials for a supplementary, algorithmic approach to lower secondary school mathematics. It consists of:
First steps in programming - sets of spirit masters
Preliminary Pack ) many cards can be used directly with calculators and
Main Pack ) many others can with modification
Extension Pack - later work, using BASIC.

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Sharp,J.M.C.
The Calculator Workbox

Addison-Wesley 1979

A boxed collection of workcards intended for 12-14 year olds. (unavailable at time of writing).

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Watson,F.R.
Exploring Numbers

Institute of Education,
Univ. of Keele 1979

Three series of cheaply produced pupils' materials with Teachers' notes. The material consists of investigations in number theory, from Primary to Upper Secondary school, which might benefit from calculator assistance.

Series A (10-13 years)
Series B (13-16 years)
Series C (16-18 years)

(Some of the more 'advanced' investigations are adaptable for younger children.)

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Watson,F.R.
BACpac: basic arithmetic with a calculator

Institute of Education,
Univ. of Keele 1981

A collection of worksheets developed from work done with low achieving secondary school children.

{see Watson,F.R. 'Promising Practices....'(p.37)}

A forthcoming, and fairly comprehensive, publication promises to be:

Kaner,P.
Integrated Mathematics Scheme
Bell and Hyman 1981

This textbook series is to offer a course for 11-16 year olds, at three levels of ability, in which the use of calculators is integrated from the start - the first such course to be produced in the U.K.
(to be published from Autumn 1981)

There are also several publications now available which include at least occasional references to the use of calculators.

Some examples are:

Avis,P.
Number Games
Cassell 1980

Four sets of number games for 8-14 year olds. Set 4 (11-14 years) includes games involving large numbers, decimals and the use of calculators.

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Holt,M., and Rothery,A.
Mathsworks 1 and 2
(with Teachers' books, workbooks and spirit masters)
Longman 1979

A collection of well-presented activities for 4th and 5th year secondary classes although much is relevant to younger pupils. Topics which include calculator activities are: number patterns, decimals and square roots.

---

Lumb,D.
Oxford Senior Worksheets: Mathematics
O.U.P. 1980

A few of the worksheets involve calculator use.

The immediate future should certainly see the appearance of more curriculum materials which assume the ready availability of calculators. In particular, three curriculum projects are due to make a significant contribution:

Leicestershire Primary Calculator Project:
(A collaboration between the Leicestershire L.E.A. and the Shell Centre, University of Nottingham).

The project, based at the Shell Centre, has so far produced some materials, especially for 7-11 year olds, in the form of workcards.
{For preliminary report see Bell et al (p.72.)}

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Schools Council: Calculators in Secondary Schools
(based at University of Durham)

Materials for use with 11-16 year olds are being developed and evaluated and are due to be published in some form in the near future. {For earlier report see Co.Durham Educ.Comm. (p.72)}.

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School Mathematics Project

Some further materials are planned for the C.S.E. band in secondary schools.
{For previous publications see SMP 1979 (p.62)}.

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In the field of in-service teacher education, two packages will be available in the near future:

School Mathematics Project
Calculators

1981?

An 'In-Service Resource Kit' aimed at teachers at secondary level. Intended for 'those with little knowledge of calculators', a variety of ideas is presented 'to enhance the teaching of maths'.

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Open University
Calculators in the Primary School

1982?

A package consisting of printed course materials and a video tape intended as a basis for courses in L.E.A's. and Colleges. Basic issues are addressed and a core of curricular ideas is offered as a starting point for work with 7-11 year olds.

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## CHAPTER 5

## RESEARCH

### (i) General

It is, perhaps, indicative of the strength of the reactions, favourable and unfavourable, to proposals for calculator use in schools that a considerable number of studies have been undertaken to determine the effects of calculator usage. At the time of writing, more than a hundred such studies have been reported, mostly American and mostly taking the form of experiments, involving calculator-using and control groups, subjected to pre and post tests.

Many of those studies have been the object of adverse criticism on the grounds of poor experimental design, and the only 'positive' conclusion to be drawn from many of them has been that calculator use does not appear to have an adverse effect on the development of computational skills, in the short term, at least.

Most studies have been in the form of unpublished doctoral dissertations reported in Dissertation Abstracts International: the available published studies are referred to below in the appropriate sections of this Chapter.

Bell,A.W. and Bishop,A.J.
Report submitted to Cockroft Committee on
research in Mathematics Education (unpublished) 1980

Chapter 13.1 'Calculators in the Classroom', makes reference to many of the principal publications and includes a survey, albeit brief, of the present state of research and development, in the U.K. and elsewhere.

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Roberts,D.M.
'The Impact of Electronic Calculators on Educational Performance'
Review of Educational Research 50, 1 1980

Thirty-four empirical experimental studies at the elementary, secondary and college level are reviewed. Generally, calculator use was shown to give some computational benefit and to have little discernible effect on conceptual development. Research designs are criticised and, it is claimed, hinder interpretation of the results.

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Suydam,M.N.(Ed.)
Investigations with Calculators: Abstracts and Critical Analyses of Research
Calculator Information Center
Ohio State University, Columbus 1979
(ERIC: ED 170 134)

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Suydam,M.N.(Ed.)
Investigations with Calculators: Abstracts and Critical Analyses of Research: Supplement

Calculator Information Center
Ohio State University, Columbus 1979
(ERIC: ED 171 585)

Forty-four studies are reported in the form of extended abstracts with critical commentaries. The strengths and weaknesses of each are discussed.

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Suydam,M.N.(Ed.)
Investigations in Mathematics Education: 12, 2 Spring 1979
(Available from Information Reference Center, Ohio State University)
(ERIC: ED 171 561)

Fourteen research reports, including two on calculators, are abstracted and analysed.

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Other discussions of present and needed research, and references to available studies are to be found in:

Blakeley,B.H.
'Calculated risks' (p.6)

Esty,E. and Payne,J. (Eds.)
Report of Conference on Needed Research .... (p.3)

Rising,G.
The New Calculation in Education .... (p.14)

Suydam,M.N.
State-of-the-Art Reviews (p.5)

Suydam,M.N.(Ed.)
Reference Bulletins .... (p.4)

Watson,F.R.
'Promising Practices ....' (p.37)

Weaver,J.F.
'Some suggestions for needed research....' {in Suydam (p.2)}

Other than the curriculum projects referred to, there has been, as yet, little research in the U.K. on the effects of calculator use.

Two studies of some relevance are:

Lee,M.J.
'How secondary school children check their work in arithmetic'
Unpublished M.Sc. dissertation
University of Keele 1979

Of relevance since checking work is all the more important when calculators are used. Checking practices used spontaneously were found not to correspond with what was taught in school.

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Thompson,I.F.
'Procedures used by children to check work done with an electronic calculator.'
Unpublished M.Sc. dissertation
University of Keele 1980
(not available at time of writing)

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(ii) Surveys

The results of a number of surveys have been published over the last four years. The most interesting and informative are certainly Palmer, Reys et al and Yvon and Downing. The overall picture presented is of a situation slowly changing in favour of the use of calculators in school.

A number of other surveys are reported in the American literature, especially in the publications of the Calculator Information Center.

Bitter,G.G.
'Calculator teacher attitudes improved through in-service education'
School Science and Maths 80, April 1980

The attitudes to calculator use of a group of elementary school teachers was measured before and after experience of a 'hands on' calculator workshop. Significant gains in attitude were recorded.

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Campbell,P. and Virgin,A.E.
A survey of elementary school teachers' and principals' attitudes to mathematics and utilising minicalculators
North York Board of Education
Willowdale, Ontario 1976
(ERIC: ED 137 121)

Of the teachers questioned, about half were in favour of introducing calculators into the upper elementary school. Most principals felt that computational proficiency should be achieved first. Details of the questionnaires are included.

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Cohen,M.and Fliess,R.E.
Minicalculators and Instructional Impact: A Teacher Survey
School of Education,
University of Pittsburgh, Pa. 1979
(ERIC: ED 178 360)

The secondary school teachers questioned generally favoured calculator use, though not as a substitute for computational skills. The school districts concerned had no clear-cut policies on the use of calculators.

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Etlinger,L.E. and Ogletree,E.J.
Calculators in the Elementary School: A Survey of How and Why
(ERIC: ED 191 741) 1981

A brief report of surveys conducted in Chicago and St.Louis in 1978-80 among teachers, administrators and parents.

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Graeber,A.O. et al
A survey of classroom practices in mathematics:
Reports of 1st, 3rd, 5th and 7th grade teachers in
Delaware, New Jersey and Pennsylvania

Research for Better Schools, Inc.,
Philadelphia, Pa. 1977
(ERIC: ED 180 821)

A broad survey of classroom practices which includes some information on teachers' use of and attitudes to calculators.

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Gregory,C.A.
Electronic Calculators in the Elementary Mathematics Curriculum
(p.8) This report includes detailed accounts of surveys of calculator ownership among children of Middle School age, and also of calculator use in their schools, in one L.E.A.

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Ogletree,E.J. and Etlinger,L.E.
Should hand-held calculators be used in Elementary School? A Survey.
(ERIC: ED 186 258)

Report of a survey of elementary/secondary school teachers and administrators during a calculator workshop. Generally, the calculator was viewed as an instructional aid and many possibilities for its use in the classroom were acknowledged.

---

Palmer,H.B.A.
'Minicalculators in the classroom - what do the Teachers think?'
Arithmetic Teacher, 25, 7 1978

A wide range of teacher reactions to a questionnaire is recorded. There was general acceptance of the inevitability of calculator use but also many reservations were expressed.

---

Reys,R.E., Bestgen,B., Rybolt,J.F. and Wyatt,J.W.
'Hand Calculators: What's happening in schools today?'
Arithmetic Teacher, 27, 6 1980

A detailed report of a survey of teachers in Missouri, of calculator policies and also of calculator ownership among children. One of the most informative surveys,in which the questionnaires and results are reported on in detail.

---

Tyler,K.
'Some comments on calculators in Junior Schools'
Mathematics Teaching 90 1980

A brief, verbatim report of the attitudes and views of some Junior School teachers.

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Yvon,B.H. and Downing,D.A.
'Attitudes towards calculator usage in schools: a survey of parents and teachers'
School Science and Maths. 78
May/June 1978
{ref.in Suydam,M.N.(Ed.) Investigations ....(pp.66-67)}

A report of a survey conducted in two towns in Maine. The general feeling was that calculators should not replace the use of pencil and paper algorithms. This feeling was strongest among teachers of younger children. However, more than half the sample reported that the man of the family used an electronic calculator at work.

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(iii) Exploratory/feasibility studies

The nature, range and depth of reportage of the studies referenced in this section vary enormously.

Of the three British studies, the S.M.P. report is certainly still of historical interest while those from County Durham and the University of Nottingham have been the starting points of on-going curriculum development projects. The outcome of the Swedish primary school experiment is not yet available, while the reports from the University of Wisconsin form part of a long-term research effort on children's understanding of algebraic operations.

Bell,A.W., Burkhardt,H., McIntosh,A. and Moore,G.
A Calculator Experiment in a Primary School
Shell Centre for Maths. Education, University of Nottingham 1978

To date, the major report of the U.K. on the use of calculators with young children. Calculators were used experimentally in one primary school with children of 5-11 years. The most valuable feature of the report is the detailed description of activities and children's responses.

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Co.Durham Education Committee
Use of electronic calculators in secondary schools 1973-76
Spennymoor Co.Durham 1976

A report of the first major feasibility study in the U.K. Apart from a discussion of practical issues, the core of the publication consists of detailed reports from the schools involved. Reactions were generally positive and many suggestions were made for calculator use in the future.

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Hedren,R.
'Hand calculators and mathematics in primary school'
Prospects 9, 3 1979
(also published in Morray,Z. and Draxler,A.(Eds.)
Mathematics for Real Life UNESCO, Paris 1979
(ERIC: ED 182 183)

A brief report, with few concrete details, of an experiment sponsored by the Swedish government to determine the consequences of calculator use in the early years. The broader issues are discussed in some depth. The present paper is a progress report and the final results of evaluation have, apparently, yet to appear.

---

Lowerre,G.P., Scandura,A.M., Scandura,J.M. and Veneski,J.
'Using electronic calculators with 3rd and 4th graders: a feasibility study?'
School Science and Maths, 78, Oct. 1978
{ref.in Suydam,M.N.(Ed.) Investigations ...(pp.66-67)}

A report on work with small groups of 7-9 year olds. Impressive gains in the tests given are claimed and there is a discussion of the topics taught and the longer term implications of calculator use.

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Scandura,A.M., Lowerre,G.F., Veneski,J., and Scandura,J.M.
'Using electronic calculators with elementary school children'
Educational Technology 16, Aug. 1976
{ref. in Suydam,M.N.(Ed.) Investigations ...(pp.66-67)}

Five feasibility studies with children from 5 years upwards are reported. A wide range of subject matter was dealt with and it is claimed that the learning of some mathematical topics was facilitated by the use of calculators.

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Scandura,J.M., Lowerre,G.F., Scandura,A.M., and Veneski,J.
'Using Electronic Calculators with Children Ages 5-7: Four Mine-Experiments'
School and Science Maths 78, Nov.1978
{ref.in Suydam,M.N.(Ed.) Investigations ....(pp.66-67)}

Some uses of calculators with very young children are explored. Details of the lessons given are briefly reported. The calculator groups are reported to have been highly motivated but altogether the study seems to have been poorly designed and conclusions drawn from very little data.

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Schmur,J.O., and Long,J.W.
'Just pushing buttons or learning? - a case for minicalculators'
Arithmetic Teacher 23, 7 1976
{Minicalculator issue: ref. in Suydam,M.N.(Ed.)
Investigations .....(pp.66-67)}

A study, of only four weeks' duration, of the effects of calculator use on the attainment of low-achieving children. It is concluded that the calculator could well have a place in the elementary school classroom.

---

SMP (School Mathematics Project)
Calculators in Schools 1977

A wide-ranging survey of the possible uses of calculators undertaken over the course of a year in several English (mainly secondary) schools. The report includes details of reactions, work done, and calculator specifications. A variety of views is reported and various unresolved questions considered. A follow-up report is appended.

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Weaver,J.F.
A Monadic Module alias a Unitary Unit

Project Paper 77-5
R & D Center for Cognitive Learning,
Univ. of Wisconsin, Madison 1977
(ERIC: ED 161 670)

Calculators (RPN) were used with an advanced 7th grade class to investigate unary operations. Included are discussion of the calculator algorithms used, and record sheets to summarise discoveries.

---

Weaver,J.F.
Some Monadic/Diadic Combos

Project Paper 77-6
R & D Center for Cognitive Learning,
Univ. of Wisconsin, Madison 1977
(ERIC: ED 161 671)

Calculators were used to explore the distributivity of a unary operator over a binary operator. Some instructional material is included.

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Weaver,J.F.
3rd Grade Students' Performance on Calculator and Calculator-related Tasks

Technical Report No.498
R & D Centre for Individualised Schooling,
Univ. of Wisconsin, Madison 1979
(ERIC: ED 176 992)

A report on further work with calculator algorithms - 'chaining' of operations and inverses - with 3rd grade students.

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Weaver,J.F., Blume,G.W., and Mitchell,C.E.
Calculator explorations with 7th grade students: Some calculator-inspired instructional materials, observations and investigations

Technical Report No.497
R & D Center for Individualised Schooling,
Univ. of Wisconsin, Madison 1979
(ERIC: ED 177 019)

A lengthy report of investigations with algebraic-logic and RPN calculators, including the use of machine-independent flow charts. It is reported that no problems were experienced with RPN calculators, there being no confusion with 'algebraic' logic.

---

Zweng,M.J.et al
Children's Strategies of Solving Verbal Problems: Final Report
NIE 1979
(ERIC: ED 178 359)

An investigation of the factors which help elementary school children to solve verbal problems - the attributes of problems, the problem transformations that were possible, and the tools used (including calculators).

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(iv) Experimental Studies

All the studies referred to in this category are American.

Blume,G.W., and Mitchell,C.E.
The Calculator's Effect on Children's Solution Processes
Paper presented to N.C.T.M. Conference, Boston, Mass. 1979
(ERIC: ED 170 166)

Several studies, covering a wide age range, of the effect of calculator use on solution methods in routine problems. The performance of 'pencil-and-paper' and 'calculator' groups was compared. It is recommended that calculator use should be accompanied by instruction to find simplifications and shorter solution methods.

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Campbell,P., and Virgin,A.E.
An evaluation of elementary school mathematics programs utilising the minicalculator

North York Board of Education,
Willowdale, Ontario 1976
(ERIC: ED 137 120)

The achievement and attitude of calculator and non-calculator groups were tested after seven months work. No significant difference in computation was found but the experimental group achieved higher scores on tests of mathematical concepts and problem solving.

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Carpenter,T.P., Corbitt,M.K., Kepner,H.S., Lindquist,M.M., and Reys,R.E.
'Calculators in Testing Situations: Results and Implications from National Assessment'

Arithmetic Teacher 28, 5 1981

A report on the results of the tests involving calculator use administered as part of the National Assessment of Educational Performance (NAEP) programme during 1977/78. The tests covered routine computation and problem solving.

---

Conner,T.J.
An Investigation of the Use of Hand-Held Calculators by Students in Elementary School

Research Monograph No.32
Florida University, Gainesville 1980
(ERIC: ED 190 355)

A report of a study of the effects of calculator use on problem solving and computational skills among 5-10 year olds. No detrimental effects were identified. The results of a questionnaire administered to parents is appended.

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Cech,J.P.
'The effect of the use of desk calculators on attitude and achievement with low-achieving ninth graders'.

Mathematics Teacher 65, 2 1972
(reprinted in Neufeld,K.A. p.15)

An early experiment with desk calculators concerned with attitudes to mathematics and the improvement of computational skills. The results were largely inconclusive.

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Creswell,J.L., and Vaughn,L.R.
'Hand-held calculator curriculum and mathematical achievement and retention'
J.Res.Math.Educ. 10 5 1979

A controlled experiment in teaching decimals and percentages to grade nine low-achievers. It was concluded that the calculator group achieved at a higher level. Few details are given of materials or activities.

---

Ethelberg-Laursen,J.
'An experiment in Danish schools'
Mathematics Teaching 82 1978

A report of a controlled experiment with four classes of eight year olds who were finally tested on mechanical arithmetic and problems without calculators. The experimental groups at least did no worse. It is emphasised that the calculator is an aid and that the teacher needs to have a clear idea of purpose.

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Gaslin,W.L.
'A comparison of achievement and attitudes of students using conventional or calculator-based algorithms for operations on positive rational numbers in ninth-grade general mathematics'
J.Res.Math.Educ. 6, 2 1975
{reprinted in Neufeld,K.A.(p.15)}

There was no significant difference in attitudes to mathematics. The groups using alternative algorithms (converting to decimals) showed, generally, greater mastery and retention of skill.

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Hopkins,B.L.
The Effect of a Hand-held Calculator Curriculum in Selected Fundamentals of Mathematics Classes
Ph.D.Dissertation,
Univ.of Texas, Austin 1978
(ERIC: ED 156 496)
{ref. in Suydam,M.N.(ed.) Investigations .... (pp.66-67)}

The experiment was designed to assess the effect on achievement and attitude of ninth grade general mathematics classes. No effect is reported on computation but the calculator group were better at problem solving. This has been rated as one of the better designed and more carefully executed studies of its kind.

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Rudnick,J.A. and Krulik,S.
'The minicalculator: friend or foe?'
Arithmetic Teacher 23, 8 1976
{ref. in Suydam,M.N.(ed.) Investigations .... (pp.66-67)}

This study set out to assess the effect of availability and use of calculators on mathematics achievement and pencil and paper calculation. A survey of parents' attitudes was also carried out. After one year the preliminary conclusions were that although the parents had many reservations, the children's attainment had not suffered.

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Shumway,R.J., White,A.L., Wheatley,G.H., Reys,R.E., Coburn,T.G., and Schoen,H.L.
'Initial effect of Calculators in Elementary School Mathematics'
J.Res.Math.Ed. 12, 2 1981

A detailed, technical report of the results of tests conducted during the one year project described elsewhere (p.79).

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Standifer,C.E., and Maples,E.G.
'Achievement and attitude of 3rd grade students using two types of calculators'
School Science and Maths 81, Jan.1981

The effects of calculator use on attitude towards mathematics and on the acquisition and retention of mathematical skills were tested. Both 'normal' calculators and pre-programmed machines were used. Although differences in attitude were non-significant the performance of the calculator group was better all round.

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Szetela,W.
'Hand-held calculators and the learning of trigonometrical ratios'
J.Res.Math.Educ. 10, 2 1979

Specially designed materials were used with students in grades 9-10. Trigonometrical tables were built up with the aid of calculators.

---

Szetela,W.
'Calculators and the teaching of ratios in grade 7'
J.Res.Math.Educ. 11, 1 80

An outline is given of the teaching materials used with groups of children over three weeks - a calculator group and a control. The calculators did not apparently hinder learning and the calculator group was reported to be more highly motivated and industrious.

---

Moser,J.M.
The effect of Calculator-Supplemented Instruction upon the Arithmetical Achievement of 2nd and 3rd Graders
Technical Report No.502
R & D Center for Individualised Schooling,
University of Wisconsin, Madison 1979
(ERIC: ED 180 764)

Over an extended period teachers used calculators in specified ways within the context of the regular curriculum. Tests on computation and place value were given to calculator and non-calculator groups. Generally there were no significant differences, though on some tests the calculator groups' performance was higher.

---

West,T.A.
'Effectiveness of two drill strategies (pencil and paper, electronic calculator) in facilitating the learning of basic multiplication combinations with factors 7, 8 or 9'
School Science and Maths 80, Feb. 1980

A report of an experiment with three groups of children from grades 4, 5 and 6 - a calculator group, a pencil and paper group and a control group. Tests on 'tables' and problems were given. All groups improved on the 'tables' test while the first two groups improved more on problems.

---

Wheatley,C.L.
'Calculator Use and Problem-Solving Performance'
J.Res.Math.Educ. 11, 5 1980

An experimental study of calculator use with children in grade 5. Strategies used were investigated as well as performance scores.

---

Wheatley,G.H., and Shumway,R.J.
Impact of calculators in Elementary School Mathematics: Final Report
Depts. of Education and Mathematics, Purdue Univ., Lafayette, Indiana 1979 (ERIC: ED 175 720)

A short version of a report of a one year study of the impact of calculators on elementary mathematics learning. The sample of children were drawn from grades 2-6, over five midwestern states. Calculator use was not found to have detrimental effects on learning. The results are discussed in some detail and the positive contribution of calculators endorsed.

---

Wheatley,G.H., Shumway,R.J., Coburn,T.G., Reys,R.E., Schoen,H.L., Wheatley,C.L., and White,A.L.
'Calculators in Elementary Schools'
Arithmetic Teacher 27, 1 1979

A shorter, popular account of the project described in the previous entry.

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## NOTES ON AVAILABILITY OF PUBLICATIONS

Some of the publications referred to in the text are only, or more easily available in the U.K., from the following sources:

Alberta Teachers' Association,
Mathematics Council,
11010-142 St.,
Edmonton,
Alberta T5N 2R1,
Canada.

ATM (Association of Teachers of Mathematics),
Market Street Chambers,
Nelson,
Lancashire,
BB9 7LN.

Calculator Information Center,
Ohio State University,
1200 Chambers Road,
Columbus,
Ohio 43212,
U.S.A.

Chelsea College, University of London,
Centre for Science and Mathematics Education,
Bridges Place,
London,
SW6 4HR.

Computer Research Press,
Abacus House,
Tunbridge Wells,
Kent,
TN4 0HU.

Consumers' Association,
Which?
1 Carton Hill,
Hertford,
SG13 7LZ.

CET (Council for Educational Technology for the United Kingdom)
3 Devonshire Street,
London,
W1N 2BA.

Durham, Co.Education Committee,
Area Education Office,
Green Lane,
Spennymoor,
Co.Durham.

ERIC (Educational Resources Information Clearinghouse)
- publications, in microfiche or papercopy form, are abstracted in Resources in Education (RIE) and are available from

EDRS (Eric Document Reproduction Service),
P.O.Box 190,
Arlington,
VA 22210,
U.S.A.

- most of those cited in the text are more conveniently obtained from

British Library Lending Division,
Boston Spa,
Wetherby,
North Yorkshire.

Fergus-Davidson Associates Ltd.,
376 London Road,
Croydon,
Surrey,
CR0 2SU.

Hamilton, Board of Education for the City of
100 Main St. West,
P.O.Box 558,
Hamilton,
Ontario L8N 3L1,
Canada.

Keele, University of

- publications by F.R.Watson available from
Institute of Education,
University of Keele,
Keele,
Staffordshire,
ST5 5BG.

Leapfrogs
- publications available from

Tarquin Publications,
Stradbroke,
Diss,
Norfolk.

Leeds, Univ. of
Centre for Studies in Science Education,
Leeds,
LS2 9JT.

L.P.Enterprises,
8-11 Cambridge House,
Cambridge Road,
Barking,
Essex,
IG11 8NT.

Mathematical Association,
259 London Road,
Leicester,
LE2 3BE.

National Council of Teachers of Mathematics,
1906 Association Drive,
Reston,
VA 22091
U.S.A.

Shell Centre for Mathematical Education,
University of Nottingham,
University Park,
Nottingham,
NG7 2RD.

SMEAC Information Reference Center,
Ohio State University.
(see Calculator Information Center)

SMP (School Mathematics Project),
Westfield College,
Kidderpore Ave.,
Hampstead,
London,
NW3 7ST.

Texas Instruments,
European Consumer Division,
Manton Lane,
Bedford,
MK41 7PU.

Texas Instruments Ltd., Technology Centres:

Book Dept.,
Knightsbridge Mall,
Arndale Centre,
Manchester.

Book Dept.,
186 High Street,
Slough,
Bucks.

Book Dept.,
126-128 George Street,
Edinburgh.

Book Dept.,
25 St.Stephen's Green,
Dublin.

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